The sleeping brain and emotional memory consolidation

An analogue investigation into the role of sleep on intrusive memory development in PTSD.

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Systematic Literature Review, Empirical Project and Service Evaluation Project

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Acknowledgments

"To be able to forget means sanity"

- *Jack London, The Star Rover*

I'm at the end of what has been an incredible journey; first a PhD and now finishing my clinical psychology training, ready to embark on an exciting career. I have been lucky enough to continue my interest in the study of memory, with a particular focus this time on how forgetting may be useful to people in the aftermath of trauma. There are several people I wish to thank: first and foremost, the wonderful group of people I have had the privilege of training with. Something felt different with our bunch and we all helped each other through; I'd like to thank all of my clinical and academic supervisors for the time they have spent helping me develop into the person I am today; to my family for supporting me whilst I dragged out even more University education; to Olivia for her patient and welcoming ears and fascinating chats about our work; and finally to my old supervisors and good friends, Chris and Steven, for believing in me and giving me the confidence to succeed in this new area.

OVERVIEW

Systematic Literature Review:

Can sleep prevent the development of PTSD symptoms? A systematic review of experimental studies examining the effect of sleep on declarative emotional memory consolidation.

Empirical project:

The sleeping brain and emotional memory consolidation: An analogue investigation into the role of sleep on intrusive memory development in PTSD.

Service Evaluation Project:

Community-based anger workshops provided by Southwark Psychological Therapy Service: Assessment of efficacy and attrition.

SYSTEMATIC LITERATURE REVIEW

Can sleep prevent the development of PTSD symptoms? A systematic review of experimental studies examining the effect of sleep on declarative emotional memory consolidation.

Main supervisor: Dr Jennifer Wild

Second supervisor: Professor Robin Morris

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Abstract

Emotional memories are at the core of post-traumatic stress disorder (PTSD), therefore it has been suggested that blocking memory consolidation processes in the aftermath of trauma may reduce the chances of symptoms developing. Research from the neurosciences confirms the importance of sleep in memory consolidation, with specific consolidation interactions occurring between different sleep stages and fractions of the memory system. This review examined whether there is sufficient evidence from recent non-clinical experimental studies to support the contention that sleep deprivation in the aftermath of trauma may be an effective behavioural intervention to reduce PTSD symptomatology. The review focused on studies examining the effect of sleep on emotional declarative memory in adults. A systematic search yielded twenty-one studies that met inclusion criteria. Results from memory tasks were overall inconsistent; some studies showed support that sleep selectively enhances emotional memories or sleep deprivation impairs this consolidation process. However, other studies provided equivocal evidence or argued against a selective enhancement during sleep. Moreover, conflicting evidence emerged for a special role of rapid eye movement (REM) sleep in emotional memory consolidation. Although sleep-related differences in emotional or neutral memory performance were not always displayed, neuroimaging studies found evidence for emotional memory consolidation at the functional level. We conclude that there is presently insufficient evidence to warrant using sleep deprivation as an early intervention strategy in PTSD. Further studies examining all aspects of memory encoding, consolidation and retrieval will delineate this ongoing clinical question and several suggestions for future research are outlined.

1. *Introduction*

Post-traumatic stress disorder (PTSD) is a chronic, disabling psychological condition which arises in a minority of people following experience with highly stressful events. Modern psychiatric classification systems emphasise that for a diagnosis to be made, a person must have had either direct or indirect contact with a traumatic stressor as well as showing evidence of re-experiencing symptoms (e.g. flashbacks and nightmares); hyperarousal; avoidance of traumatic reminders and emotional numbing. In some recent conceptualisations of the disorder, PTSD is believed to arise principally through the consolidation of the explicit memories for such events (Rubin, Berntsen, & Johansen, 2008). Consolidation here refers to the ongoing post-acquisition stabilization of a memory (Dudai, 2004, p. 52). Understanding the mechanisms by which emotional memories develop, consolidate and later become pathogenic is of theoretical and clinical significance.

Current best evidence for psychological treatments of PTSD reflect the centrality and importance of the emotional memory in this disorder since therapies that focus on elaborating the memory or exposure to it are found to provide the most symptomatic relief (Bisson & Andrew, 2007; Bisson et al., 2007). However, clinical and experimental research has primarily focused on emotional memory encoding of the trauma (i.e. cognitive processing during trauma) and memory retrieval (i.e. treating re-experiencing and other symptoms via exposure to the memory). Much less attention has been paid to the consolidation phase.

The past twenty years has seen an expansion in our knowledge of how sleep is involved in memory consolidation (Stickgold & Walker, 2007; Walker, 2010). Sleep is measured in the laboratory using polysomnography (PSG) which involves recording a number of electrical potentials arising from the scalp and face, as well as detecting eye movements. The PSG recording can be classified into different stages of sleep using standardised scoring criteria (Rechtschaffen & Kales, 1968). Humans fluctuate between non rapid eye movement (NREM) and rapid eye movement sleep (REM), with NREM further divisible into four stages: stage 1 and 2, and stages 3 and 4 being termed slow-wave sleep (SWS). These stages are primarily distinguished based on the electroencephalogram (EEG) patterns they emit, with different amplitudes and frequencies. For example, SWS is characterised by strong activity in the delta band (1-4Hz) whereas REM sleep is characterised by theta waves (4-8Hz), similar to that of waking activity. The existence of these natural demarcations in the sleep cycle naturally led to the hypothesis that each is more or less responsible for a given neurobiological process; research has thus focused on how different types of memory are consolidated during these

alternating stages of sleep. For example, non-emotional declarative memory is related to SWS sleep, and procedural and emotional declarative memory have been related to REM sleep (Diekelmann, Wilhelm, & Born, 2009). It is increasingly acknowledged, however, that there may be more of an interaction between the sleep stages and this way of classifying sleep is rather crude (Conte & Ficca, 2013).

Cognitive models of PTSD suggest that trauma itself is insufficient for PTSD symptoms to develop and that the individual's reaction to the trauma is more predictive of who will develop PTSD than trauma exposure per se (Bernat, Ronfeldt, Calhoun, & Arias, 1998; Declercq, Meganck, Deheegher, & Van Hoorde, 2011; Rasmussen, Rosenfeld, Reeves, & Keller, 2007). It appears that the emotional memory of an event (or events) represents the nucleus of the problem (Rubin et al., 2008). Processes linked to memory consolidation primarily operate during sleep, working to actively strengthen emotional memories (Born & Wilhelm, 2012; Ellenbogen, Payne, & Stickgold, 2006). Based on this knowledge, it has been suggested that disrupting or preventing sleep may have a therapeutic effect on the development of PTSD (Holland & Lewis, 2007a). A naturalistic test of this hypothesis has been put forward in the context of traumatic brain injury (TBI), where the development of PTSD can be assessed alongside objective residual details for the traumatic event (Gil, Caspi, Ben-Ari, & Klein, 2006; Klein, Caspi, & Gil, 2003). This research shows some support, as it appears that the rate of PTSD is sometimes lower in those people without an explicit memory of the trauma. However, the neurobiological and neuropsychological sequelae of a head injury preclude us from extrapolating these results to the general population, and they do not allow us to make conclusions regarding the role of sleep in the consolidation process. In the current review we aimed to extend this research by examining data from experimental studies in non-clinical samples to address the following clinical question: *Can preventing or disrupting sleep directly after the acquisition of a traumatic memory prevent PTSD symptomatology?*

A number of narrative review articles have provided a synthesis of the results from experimental studies examining sleep-dependent memory consolidation. However, existing reviews have adopted a more theoretical rather than clinical focus, meaning their conclusions have tended to be vague or speculative with respect to the question at hand here. One notable exception to this is the 'sleep to forget, sleep to remember' (SFSR) model (Goldstein & Walker, 2014; Walker & van der Helm, 2009; Walker, 2009) which has been developed based on the findings of several existing studies. In their most recent review, Goldstein and Walker (2014) make explicit reference to how their model of sleep-dependent memory consolidation may relate to both PTSD and major depression. They discuss how emotional memories are more salient than neutral ones due to the cascade of stress hormones released in the brain and their

subsequent effect on memory consolidation via neuromodulation within the basolateral amygdala, an area in the brain well known to be responsible for emotional processing (McGaugh, 2004). Over time, the central episodic details of these events are remembered far better than benign neutral events in our lives, but impressively they are no longer accompanied by the same affective tone upon their retrieval. The SFSR model provides an explanation for this gradual separation of affect and memory. The SFSR posits that REM sleep in the aftermath of emotional events serves the function of diminishing the affective tone that is fused with the encoded memory trace; under optimum sleeping conditions, the neurophysiological environment created by REM allows a depotentiation of emotional strength whilst allowing the disparate sensory representations of that event to be consolidated. Thus, we sleep to *forget* the initial arousal and subjective distress associated with an experience, yet we sleep to *remember* the details of the event. The adaptive function of this process can easily be formulated: the detrimental effects of anxiety and high arousal associated with a traumatic event are diminished but we are left with an accurate memory of the event to help guide us safely in future similar circumstances. When REM sleep is disrupted and this process does not occur, the affective blanket remains and the event details are unable to be consolidated into the autobiographical memory network. Thus, this model predicts that sleep and in particular REM sleep, is crucial for the natural therapeutic dampening of emotional reactivity of an aversive event whilst helping store it in the brain for future use.

Although the SFSR makes testable predictions and provides a highly useful theoretical framework, there still remain many conflicting findings in the literature, especially given that the idea of therapeutic sleep deprivation was initially borne from other empirical evidence (e.g. Wagner et al., 2001; 2006). These hypotheses therefore make opposing predictions regarding the processes occurring on this first crucial night of consolidation. We therefore adopted a systematic approach to selecting studies that may be informative on this matter, which has not yet been achieved with existing review articles. In the present article we review the literature on sleep and emotional memory consolidation and attempt to draw together findings to help answer the clinical question outlined above. We anticipated there to be conflicting evidence, so a chief aim was also to identify ways in which this literature could develop to settle some of these discrepancies, again with a specific focus on PTSD. Because of the enormity of this field of research, we focus on declarative (i.e. explicit) rather than non-declarative (i.e. implicit) memory. Thus, our article focuses on how sleep affects consolidation of declarative emotional memories.

Many previous studies of sleep and memory consolidation mention how their results may relate to the development of PTSD symptoms. Here we specifically synthesise these data. In

summary, the following review makes a first attempt to draw together the seemingly disparate findings in a growing area.

2. *Method*

2.1 *Search strategy*

Searches were conducted through Web of Knowledge (WOK), PsycINFO and Ovid Medline between January 1990 - December 2014 using the search terms ((sleep and emotion* memor* and consolidat*) or (sleep and fear and learning)) not (animal or rat* or rodent or mice or mouse). Searches were limited to English language, peer reviewed journal articles.
Following removal of any duplicates, titles and abstracts were scanned with those not meeting inclusion criteria or falling under exclusion criteria were discarded; in cases where abstract information left ambiguity, full-texts were scanned to make a final decision. We also hand-searched recent review articles and reference lists of included studies.

2.2 *Inclusion and Exclusion criteria*

Studies were deemed eligible if they met the following criteria: *Inclusion* - Experimental studies in humans examining the effect of sleep on emotional memory consolidation; this had to be in the form of declarative memory with clearly defined encoding/learning phases followed by a sleep manipulation or recording, then subsequent test(s) for previously encoded stimuli. Moreover, studies had to utilise an experimental design that allowed inferences to be drawn about the effect sleep has on memory performance. *Exclusion* – animal studies; studies involving children or adolescence; studies incorporating clinical samples; studies where hormones or chemical compounds are administered to alter natural sleep activity; studies in which memories are reactivated during sleep; non-declarative memory studies; and studies primarily focusing on differences in emotional reactivity following sleep. We made the decision to exclude studies in these categories to enable the review to retain a clear focus on one aspect of this interrelated literature.

3. *Results*

The search and exclusion process are displayed in Figure 1. A total of 381 articles were retrieved (WOK = 139; PsycINFO = 211; Medline = 31). In each of the 21 final studies, we chose to extract the following information: study design and sleep manipulation; details of encoding or learning task; details of memory task; overall memory results; effect of sleep on memory;

and any other important sleep related findings, such as additional neuroimaging or neurophysiology analyses. A detailed summary of this information is provided in Table 1.

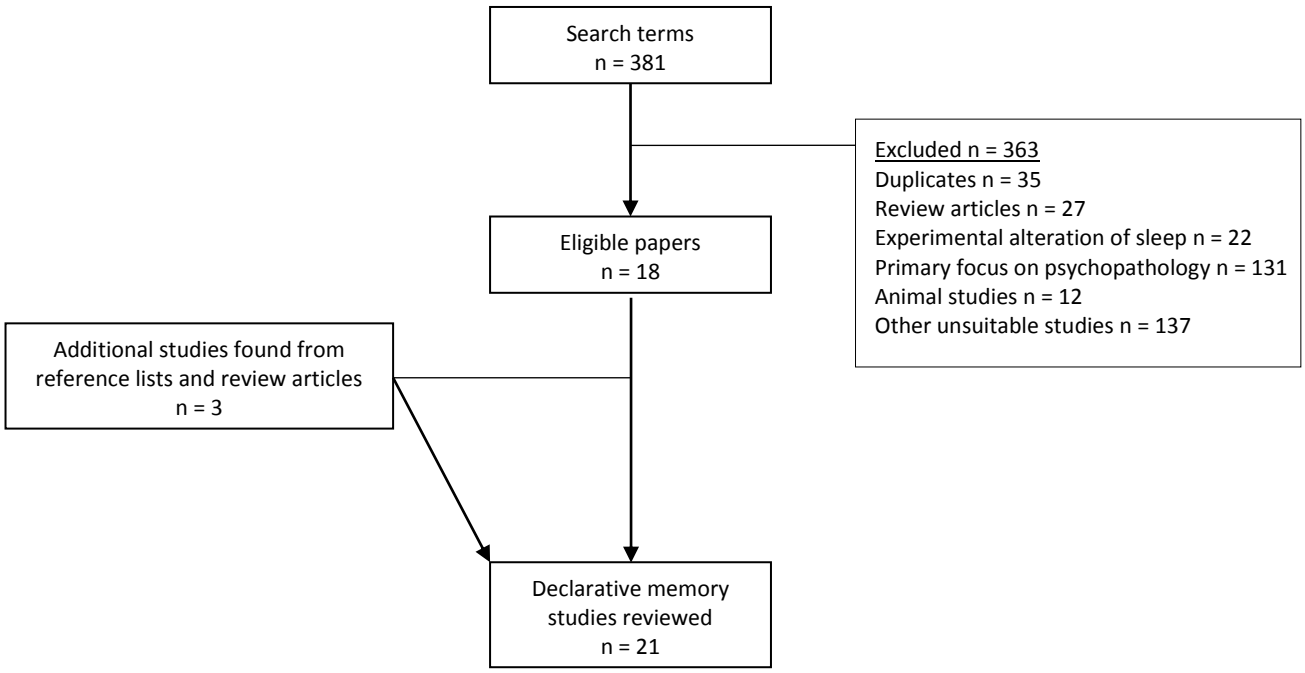

Figure 3. Search flow diagram illustrating process of selecting studies.

3.1 *Summary of methodologies*

Before describing the major findings from the reviewed studies, we first provide a brief overview of the main methods employed.

3.1.1 *Memory tasks*

Declarative memory has largely been assessed via old/new recognition tasks, in which a number of previously studied emotional and neutral images are later displayed intermixed with unseen, new images. Participants then indicate whether they have previously seen the image. Approximately half of the studies we selected have used an incidental (i.e. a surprise) recognition task, and the other half used intentional encoding, where participants know the material will later be tested. The number of encoding items fluctuated between studies as did the presentation rate, although this was generally quite brief in the order of a couple of

seconds. Importantly, the instructions during encoding of items varied substantially. Although stimuli are often already categorised along valence and arousal dimensions to create sets of 'negative' or 'neutral' items, the most common encoding instruction is to provide subjective ratings of valence and arousal for each image. By obtaining these ratings for items during the test, a measure of emotional reactivity is yielded alongside memory performance. Other judgments have also been used, such as deciding whether the image is indoors or outdoors, or whether the participant would approach or avoid the scene. Some studies did not provide any specific encoding instructions. This variation inevitably gives rise to differences in the depth of processing of material – long known to affect later memory performance (Craik & Lockhart, 1972).

Following an intervening period of sleep or wake, recognition tests are predominantly deployed only once, although several studies used a multiple testing format. Some studies incorporated Tulving's (1985) remember/know (R/K) paradigm, which helps to make an important distinction between the subjective experience associated with different declarative memory processes: Remember responses are thought to reflect the subjective experience of an all-or-nothing hippocampus driven recollection processes, whereas Know responses are thought to reflect an extra-hippocampal based familiarity process that lies on a continuum of trace strength (Yonelinas, 2002). The reason for the lack of variation in memory tasks is almost certainly due to the fact that single item encoding and recognition paradigms allow a tighter control of variables such as stimulus valence and arousal; this is reflected in the fact that the International Affective Picture System (IAPS) data set of standardised emotional pictures (Lang, Greenwald, Bradley, & Hamm, 1993; Lang, Bradley, & Cuthbert, 2005) is by far the most preferred collection of stimuli used in this research area. Exceptions to this are Wagner et al.'s (2001) study assessing free recall accuracy of emotional texts; a programme of research by Kuriyama et al. (2010; 2011; 2013) in which videos, rather than pictures, were encoded and subsequently tested via old/new recognition of still images; and two groups who opted to use associative memory tasks combining objects with backgrounds (Lewis, Cairney, Manning, & Critchley, 2011; Payne, Stickgold, Swanberg, & Kensinger, 2008).

3.1.2 *Sleep paradigms*

There are a number of experimental paradigms used to examine the effect of sleep-dependent consolidation processes:

Laboratory vs. Naturalistic settings. The majority of studies used a sleep laboratory, where PSG data are recorded. This allows researchers to complete more fine-grained analysis of the relationship between specific sleep stages and memory performance. The method is not

without its problems however, as the artificial setting of the laboratory is associated with impairments in performance, lower mood, and reduced sleep time and efficiency (Paterson, Dorrian, Ferguson, Jay, & Dawson, 2013). Naturalistic designs can overcome this, where participants are given Actigraph devices to measure basic sleep parameters such as total sleep time and efficiency via wrist movements (Ancoli-Israel et al., 2003; Sadeh & Acebo, 2002). In these designs, participants attend the laboratory for the encoding and retrieval phases of the study.

Correlational methods. By obtaining PSG recordings it is possible to compute Pearson's correlations between different sleep parameters such as time spent in different sleep stages and later memory performance. As well as electrophysiological recordings (EEG), functional magnetic resonance imaging (fMRI) data can also be acquired, allowing correlations between changes in neural activity, sleep and memory performance.

Sleep deprivation vs. sleep control. Some studies utilise total sleep deprivation (TSD) in which subjects learn material and then remain awake until the following night, before being tested a number of days later. This is compared to performance in subjects allowed to sleep normally. The delay before testing is incorporated so that sleep-deprived subjects can acquire adequate rebound sleep, thus reducing any potential influences of tiredness or vigilance on performance. Differences in performance provide inferences about sleep's general role in consolidation. Another method is to use selective sleep deprivation. This involves researchers waiting until PSG recordings indicate the subject has entered a specific sleep stage, after which they awake the person. This process is repeatedly continuously throughout the night. For example, Morgenthaler et al. (2014) selectively deprived some subjects of REM sleep, and awoke control participants in NREM sleep to control for the effects of awakening during the night.

Early vs late sleep. Selective sleep deprivation as described above has been criticised due to the stress imposed on the participant leading to corresponding rises in cortisol which are known to affect cognitive function (Vertes & Eastman, 2000). An alternative method is to use the split-night paradigm, first documented by Yaroush, Sullivan, and Ekstrand (1971). In this paradigm, early-sleep and late-sleep conditions are compared: in the early-sleep condition, participants are presented with to-be-learned information shortly before normal bedtime and then sleep for approximately 3hrs, before being woken and then presented with a memory test. In the late-sleep condition, participants go to bed at normal time for 3 hours, are then woken to complete the encoding session, and sleep for another 3hrs before being tested in the morning. This method capitalises on the fact that early sleep is rich in SWS and late sleep

contains a much higher proportion of REM. Thus, inferences can be drawn about the relative contribution of these different stages depending on performance in each condition.

12 hr sleep vs wake. A commonly used paradigm is to compare conditions in which participants are either provided a sleep opportunity following learning at night, or an equivalent period of wakefulness. In the sleep group, encoding occurs at night and is followed by sleep and subsequent test in the morning; the wake group completes encoding in the morning and is tested 12 hours later following a day of wakefulness. This method is particularly subject to the influence of circadian rhythms – cognitive and physical changes occurring during the day due to our body's biological clock. Measures of alertness and vigilance are often used to provide some control for this. Better performance in sleep groups has also been suggested simply to be a result of a lack of sensory interference occurring during the 'shelter' of this offline brain state. However, this argument can be rebutted when it can be demonstrated that specific sleep stages are linked to enhanced memory, as in the split-night paradigm described above, or if PSG correlational data are used alongside a 12hr sleep/wake paradigm to indicate an association between EEG patterns and memory performance in one group. Moreover, if only certain types of memory are enhanced following sleep (e.g. emotional vs. neutral), this also argues against a simple interference account because it suggests sleep is actively doing something to benefit this type of memory rather than just passively protecting it. Studies have also incorporated tests at different points to counter this argument; for example, testing participants again after 24hrs so that both groups have experienced equivalent periods of sleep and wakefulness, albeit at different points (e.g. Payne et al., 2012).

Nap paradigms. Although the majority of studies elect to use overnight paradigms, several have compared groups provided with a 90 minute PSG recorded nap opportunity vs. equivalent period of wakefulness. Encoding occurs just before the nap/no-nap, and memory is tested after a few hours. This method allows control over time-of-day effects, but a limitation is that participants are often unable to achieve REM sleep.

Table 2. Detailed summary of studies extracted for review.

Authors	Sleep paradigm	*Memory task* and general results	*Sleep effects on memory*	*Other major sleep related findings*
Wagner et al. (2001)	Between-subjects early (SWS) vs late (REM) sleep	*Learning of emotional and neutral text with free recall.* *Assessed percentage of content words recalled:* Emotional texts > neutral at immediate/delayed recall.	Retention over sleep > wake. Retention over early half > late half. Only emotional text retention benefited from sleep, and found only in the late half of the night.	N/A
Hu et al. (2006)	Within-subjects 12 hour wake during day vs. 12 hour sleep opportunity	*IAPS pictures with R/K paradigm.* For *d'*: R&K judgments better for arousing, over neutral stimuli. For *C*: R&K judgments sig more conservative for neutral pics. Effect size always bigger for R results.	For *d'*: K judgments, arousing > neutral after sleep, but not wake (42%↑compared to wake). R judgments, no diff for sleep vs wake in arousing vs neutral stimuli For *C*: No diff in bias for K across sleep vs wake; bias sig ↑ for R judgments on both arousing and neutral stimuli after sleep compared to wake (i.e. sleep makes you more conservative).	N/A
Wagner et al. (2006)	Between-subjects early (SWS) vs late (REM) sleep	*3AFC recognition with selection of previously learned text topics from Wagner et al. (2001).* Overall text recognition above chance.	Sleep after learning enhanced long-term memory of only emotional texts; no difference in sleep/wake for neutral text memory.	N/A
Sterpenich et al. (2007)	Between-subjects sleep control vs one night of total sleep deprivation	*IAPS pictures with R/K paradigm and fMRI.* TSD had sig ↓ overall hit rate, but *d'* not different. *C* more conservative in sleep control group. Main effect of emotion on hits. Main effect of memory type (R vs. K) and interaction suggests emotional items better remembered than neutral and -ve>+ve. -ve pictures induced more K responses than +ve.	Main effect of sleep for neutral and +ve stimuli but not -ve. Emotional items not better recognised after sleep but recollection of +ve and neutral items sig less after TSD – no difference in -ve items, or K responses. No group difference in *d'* but *C* shows TSD sig more conservative in responding.	Responses elicited by successful recollection of stimuli, irrespective of emotional valence, were significantly ↑ in sleep control than in TSD group in the MPFC and in the hippocampus. Different pattern of activation for recollection of -ve items in each group, with TSD showing more amygdala activation and sleep group showing more distributed hippocampo-neocortical pattern. This pattern determined by individual memory performance for +ve items. Overall, emotional items show more activation in hippocampus and cortical areas in sleep group, and are limited to amygdala in TSD.
Atienza & Cantero (2008)	Between-subjects sleep control vs one night of total sleep deprivation	*IAPS pictures then two-step R/K paradigm one-week later.* For *d'*: R judgments - emo > neutral; K judgments - neut. > emo. For *C*: R judgments conservative to neut items;	Main effect of TSD only in R judgments for *d'* and *C*. No sig. interaction but mean diff in neutral images 41% higher in control for R judgments (emo not worse) Hence, no consolidation benefit of emotional items after sleep.	R *d'* decreased about 22% after TSD. No interaction in valence or arousal with sleep.

		K judgments conservative to emo items. PDP-R affected by emotional content; PDP-R memory 58% in controls – PDP-F the same. PDP-R index < TSD group. PDP-R same as R judgments; some difference in PDP-F and K judgments in arousal.		
Payne et al. (2008)	Within-subjects 12 hour wake during day vs. 12 hour sleep opportunity	*Encoding of scenes with neutral or -ve foreground content.* *Specific recognition' score calculated where subjects respond same to same items; 'overall recognition' score includes items designated 'similar' that were in fact the same.* No difference in recognition between morning and evening groups, eliminating potential of circadian effects. Performance better after 30mins than 12hrs. Interaction suggests regardless of delay, -ve objects better recognised than associated background, whereas no difference in neutral items – i.e. emotional memory trade-off.	-ve but not neutral objects better recognised after sleep; no benefit of sleep in remembering backgrounds.	Neutral objects and background have same performance regardless of delay of 30min, 12hr wake or 12hr sleep. Memory for -ve components shows different pattern with time awake leading to sig ↓in performance, and memory for backgrounds ↓over sleep but memory for objects sig ↑.
Nishida et al. (2009)	Between-subjects 90 minute nap vs no nap in the afternoon	*Two sets of IAPS pictures learnt 4hrs and 15 mins prior to test, with old/new recognition.*	Nap group had sig ↑ *d'* for 4hr old emotional items vs 15 min old items. No difference in No-Nap group. No difference for neutral items in either group. Second experiment confirms findings using intervals of learning over 2 days: only emotional items show consolidation benefit.	Sleep-stage values correlated with offline diff in emotional recog memory (4h retention - 15min retention). REM% and REMmins sig correlate with offline recog benefit; shorter latency to REM, higher the emotional memory advantage.
Sterpenich et al. (2009)	Follow-up from Sterpenich et al. (2007)	*IAPS pictures from Sterpenich et al. (2007) with R/K and fMRI 6 months later.* Significant ↓in performance for R responses in both groups between 3 day – 6 month interval. Emotional items better remembered at 6 months. Sig ↑F responses. For recollection, -ve> +ve> neutral items. None for F.	No sig effect of sleep on hits after 6 months.	Sleep group showed sig ↑in recollection related activity for -ve items in fronto-parietal and amydalo-occipital networks, whereas TSD group had no greater activation in any areas – suggests separate long-term recollection and emotion pathways, with progressively less involvement of hippocampus over time. Also, evidence for different part of amygdala being involved at 6 months. Recollection to -ve vs. neutral items shows larger difference after 6 months but only in sleep group.
Kuriyama et al. (2010)	Between-subjects sleep control vs one night of total	*Motor vehicle accident (MVA)/neutral films with old/new recognition, subjective fear rating and SCR*	Sleep did not improve explicit memory.	Subjective fear rates only diminished on day 3 in TSD group for SAFE pictures, not MVA ones.

	sleep deprivation	*on days 1, 3, 10.* No group diff; effect of context found – no diff in MVA vs SAFE on day 1, but sig diff on day 3 (MVA > SAFE).		Sleep control group show odd pattern of↑SCR to MVA image misses on Day3, whereas TSD groups SCR just goes down for all contexts on missed items.
Kuriyama et al. (2011) – Gender differences	Manipulation of encoding and test before or after habitual sleep onset period (SOP)	*Emotional movie/neutral documentary with old/new recognition of still images tested before, or after SOPs and after sleep.* Pre or post SOP had no effect on overall recog ability, but sex differences found. Women's recog accuracy for aversive stimuli better in post-SOP group; in men, overall recog accuracy better in pre SOP but no diff in aversive or neutral between pre or post-SOP.	No diff in recog accuracy between 1st and 2nd test in either group, so no deleterious effect of delaying/interfering with sleep in post SOP group.	N/A
Lewis et al. (2011)	Between-subjects 12 hour wake during day vs. 12 hour sleep opportunity	*Contextual memory paradigm with neutral foreground objects superimposed on neutral or -ve background images (contexts) from IAPS battery. Context and object memory measured immediately (x2, with feedback) and at delay with fMRI. Forgetting rate = immediate-delayed.* No diff in immediate performance between groups, with -ve objects/context better remembered – time of day had no effect on encoding.	Context memory sig ↑ for sleep group. Performance ↑for –ve contexts but no group diff. Suggests that the behavioural component of the context memory task does not probe those aspects of emotional memory which are selectively facilitated by sleep. Second experiment with nap paradigm (Nap vs. No-nap) confirms main findings, eliminating circadian confound of Experiment 1.	Interaction between valence and retention type (sleep/wake): there was an ↑in responses in the Sleep group compared to Wake within 5 regions. Strongest was in right anterior parahippocampus, also in left amygdala, VMPFC, posterior cingulate and precuneus. Connectivity analysis revealed ↑coupling between parahippocampal and amygdala regions during successful emotional memory retrieval following overnight consolidation.
Payne & Kensinger (2011)	Between-subjects 12 hour wake during day vs. 12 hour sleep opportunity	*Encoding of scenes with neutral or -ve foreground content with old/new judgment to images of objects and backgrounds and fMRI.*	Sleep preferentially benefitted memory for emotional objects but not backgrounds.	After wakefulness, widespread activity found in the lateral prefrontal and parietal cortices as well as the MTL—corresponded more strongly to successful retrieval of -ve items in the wake vs. sleep group. Conversely, a more refined network—including left amygdala, VMPFC, and cingulate gyrus showed a stronger relation to successful retrieval of -ve relative to neutral items after a period of sleep. After sleep, the amygdala had a stronger +ve influence on the hippocampus and on the VMPFC than it did after wake. Connectivity changes specific to -ve items.
Baran et al. (2012)	Between-subjects 12 hour wake during day vs. 12 hour sleep opportunity	*IAPS pictures with valence/arousal and old/new recognition.* For hits: -ve > neutral. For *d'*: -ve > neutral. For *C*: more conservative for neutral rather than –	For hits: sleep > wake, but no interaction with valence. FAs: sleep group < wake. For *d'*: sleep > wake but no interaction with valence. For C: no diff between sleep and control.	Arousal ratings ↓ in non-PSG group (better sleep?) Gender and sleep quality did not alter main results when added to ANOVA model. Emotional reactivity: Wake group's ratings of valence &

		ve pictures.	No relationship between REM sleep time and hits for –ve pictures or change in valence & arousal. REM time in 3rd & 4th quarters of night: Sig –ve correlation between REM3rd and change in valence (↑REM =↓attenuation, so it preserves negativity). No correlation with arousal, or with REM4th or REM latency. No relationship between NREM stage 2 or SWS on behavioural measures.	arousal for –ve images sig attenuated compared to sleep. No diff in neutral pics. Memory performance not related to change in valence or arousal over sleep/wake. Circadian groups showed that morning/evening alone did not affect memory performance or valence, but arousal ↓sig over 12h of wake, but not sleep.
Payne et al. (2012) Experiment 1	Single group correlational design with one night PSG	*Encoding of scenes with neutral or -ve foreground content with old/new judgment to images of objects and backgrounds.* Recognition of -ve objects>neutral objects but memory for the backgrounds that contained these was sig ↓ than for neutral pairings.	Correlations show that overnight memory for emotional objects has +ve association with both the total REM time and REM% during night, with no other sleep stages showing relationship.	N/A
Payne et al. (2012) Experiment 2	Between-subjects evening vs morning group with 24 hour delay to test	*Same as Exp 1 but with a 24 hour delay.*	-ve, but not neutral, objects were better remembered in the Sleep First condition than in the Wake First condition. Backgrounds associated with -ve objects more poorly recognised following Sleep First. Emotional memory trade-off only seen in Sleep First group.	Results combined with Payne et al. (2008) to examine all delays (30 min, 12 h Sleep, 12 h Wake, Sleep First, Wake First). -ve object memory ↑after sleep but memory for background deteriorates. Steady decline seen in neutral objects and backgrounds regardless of delay.
Groch et al. (2013)	Within-subjects early (SWS) vs late (REM) sleep	*IAPS pictures with judgments of confidence; emotionality; valence; and arousal.* Hits rated as highest confidence in 76% of cases vs 16% FAs. Only high confident responses analyses.	For Hits-FAs: –ve > neutral images only in late-sleep condition – this is only for ↑ confidence responses though, as no sig diff when including ↓ confidence. REM sleep enhances recog of –ve emotional pictures compared to neutral. REM sleep (in REM condition) correlated with hit-FA of emotional images as well as with valence of emotional images. This result not explained by correlation with overall sleep time.	Valence and arousal ratings for hits, correct rejections (CR), and hits-CRs were not different between SWS&REM sleep conditions. ERPs: Enhancement in frontal positivity to old –ve pictures compared to CR of new –ve pictures was greater after late REM-rich than after early SWS retention.
Kuriyama et al. (2013)	Between-subjects sleep control vs one night of total sleep deprivation	*MVA/neutral films with directed forgetting (DF) and directed remembering (DR); test with old/new recognition (days 1&3), and SCR.* Explicit memory: Significantly ↑ recog accuracy (%) for MVA images. DF reduced accuracy of old images but increased accuracy for new; DR had opposite effect. Accuracy for MVA and NEW remained high over	Explicit memory: SD had no effect on event recognition accuracy regardless of encoding condition (DR/DF) or context (SAFE/MVA). Implicit emotional response: SD dramatically reduced SCR for DR group for all contexts. For DF, SCR was high in all contexts and SD enhanced SCR across all.	DR group had ↑SCR than DF for MVA films.

		days but SAFE was reduced. For *d'*: Sig ↑ in DF group; sig ↑ *d'* on Day 1 vs Day 3. For *C:* Sig ↑bias in DR group; more bias found in MVA images.		
Sawangjit et al. (2013)	Between-subjects 90 minute nap vs no nap in the afternoon	Implicit emotional reaction: For SCR, DF > DR. No SCR difference between contexts or in relation to recog accuracy – so generalised fear to MVA,SAFE,NEW. *In-house images with neut/+ve/-ve items and moderate/high arousal. Old/new recognition with immediate and delayed test occurring after nap with PSG or no-nap 5.5 hours later.* For immediate Hits-FAs: no diff between groups and emotional items ↑performance.	For Hits-FAs: neutral item memory deteriorated only in no-nap group; non-sig ↓in +ve item memory in both groups; sig ↓in high arousal –ve item memory in Nap group but diff between groups non-sig.	Naps predominated by stage-2 sleep with little SWS and no REM. Neutral item memory retention correlated with stage-2 sleep only; no sig correlations with –ve or +ve item retention and other sleep parameters.
Cairney et al. (2014)	Single group correlational design with one night PSG and imaging	*Two sets of IAPS pictures - before and after sleep, with R/K paradigm and fMRI. Only successful R responses analysed in a 2 (remote vs. recent) x 3 (+ve, -ve, neutral) repeated measures analysis*. For *d'*: No difference between recent/remote performance on R or R+K combined responses and no diff between +ve/-ve/neutral items.	SWS correlated with -vely valenced items' memory (r=.57). REM had –ve correlation with +ve items' memory (r= -.58). No other correlations found between SWS, REM and behavioural measures. No group difference between recent/remote performance and no difference between valences.	SWS activity ↓ in right hippocampus during recollection of -ve images; no other findings for +ve/neutral items in hippocampus. REM not associated with any change in recollection for any items. Connectivity: SWS predicts reduction in connectivity between right hippocampus→left caudate for remote –ve items; REM predicted increase between right hippocampus→superior frontal gyrus for remote –ve items. No SWS/REM predictors for other items.
Cunningham et al. (2014*b*)	Between-subjects 12 hour wake during day vs. 12 hour sleep opportunity	*Incidental vs informed encoding of scenes with neutral or -ve foreground content with old/new judgment to images of objects and backgrounds.* Objects better recognised than backgrounds following 'expectation' instruction. Emotional memory trade-off replicated, and magnitude sig ↑ following 'expectation' instruction.	When test unexpected, only sleep group had ↑memory for -ve objects. When test was expected, only the wake group had a sig ↑ of -ve scenes compared to unexpected test group. For sleep group, no difference found in trade-off regardless of whether test was expected or not.	N/A

Morgenthaler et al. (2014)	Between-subjects selective REM deprivation (REMD) and within-subjects day of wakefulness condition	*IAPS pictures with old/new recognition.* For Hits-FAs: emotional pictures > neutral.	For Hits-FAs: Recog accuracy higher overall following sleep; sleep enhances recog memory but not selectively for emotional pics and not selectively during REM.	REM-D group had 5min compared to 58 mins mean total REM over course of night.

Note: SWS = slow wave sleep, REM = rapid eye movement, PSG = polysomnography, TSD = total sleep deprivation, SCR = skin conductance response, R/K = Remember/Know paradigm (Tulving, 1985)**,** IAPS = International Affective Picture System (Lang, 1997), AFC = alternative forced choice recognition, MPFC = medial prefrontal cortex, VMPFC = ventromedial prefrontal cortex, ERP = event-related potential.

3.2 *Synthesis of findings*

The main focus of our synthesis is to consider whether or not the behavioural findings of the reviewed studies provide evidence that supports the view that sleep deprivation would be helpful in preventing the development of PTSD symptoms. Therefore, our main consideration is the extent to which sleep affects emotional memory consolidation. Many of the studies find at least some support that a period of sleep – nocturnal, or nap - enhances recognition memory performance for previously studied negatively valenced emotional stimuli (Baran, Pace-Schott, Ericson, & Spencer, 2012; Cunningham, Chambers, & Payne, 2014; Groch, Wilhelm, Diekelmann, & Born, 2013; Nishida, Pearsall, Buckner, & Walker, 2009; Payne, Chambers, & Kensinger, 2012; Payne, Stickgold, Swanberg, & Kensinger, 2008; Payne & Kensinger, 2011; Wagner, Gais, Born, & Lu, 2001; Wagner, Hallschmid, Rasch, & Born, 2006). For the purposes of answering our review question we have grouped the studies in a pragmatic way; we summarise the behavioural results in terms of those that delineate a specific memory process; those investigating encoding mechanisms; investigation of specific stages of sleep; and some further behavioural results that indicated no significant sleep related findings. We also consider the neuroimaging data provided by these studies. In practice, a number of the articles' results span several of these areas and are therefore discussed accordingly.

3.2.1 *Specific memory processes*

3.2.1.1 *Recollection and Familiarity*

In a study by Hu et al. (2006), the difference between subjectively remembered vs. known emotionally arousing and neutral IAPS images was investigated using the 12hr sleep/wake paradigm. The authors found recognition discriminability (*d*'[1]) for emotionally arousing items was significantly better than neutral items following sleep, but only for know responses – reflecting underlying familiarity processing. Additionally, recognition memory bias (*C*) was significantly more conservative to emotionally arousing stimuli following sleep compared to wake but only for remember responses. This is interesting because emotion is known to enhance the subjective sense of recollection (Phelps & Sharot, 2008) and an earlier study by Drosopoulos, Wagner and Born (2005) found an improvement in recognition memory related to increased recollection during the early, SWS rich part of the night compared to the latter

[1] *d*' is a commonly used measure in memory research based on signal detection theory (Macmillan & Creelman, 1990); it is a measure of discriminability (old vs new), whereas *C*, another commonly used measure, gives an estimate of response bias (e.g. conservative or liberal depending on tendency to respond yes or no to items).

REM sleep dominated period. Thus, it appears there may be a dissociation in the extent to which these dual processes affect recognition memory retrieval dependent on the relative valence/arousal of material and stage of sleep. Although Hu et al.'s (2006) study did not involve sleep deprivation, standing alone, their results suggest that memory for emotional information is enhanced following sleep, and this is most accurately processed by a parahippocampal based familiarity mechanism.

In a more recent study employing the R/K procedure, Cairney et al. (2014*a*) compared memory performance for materials encoded before and then after (termed 'remote' and 'recent', respectively) a night of PSG recorded sleep in all participants. Their data indicate no remote-to-recent difference in performance between positive, negative or neutral items, or between remember and know responses, suggesting no behavioural benefit of an offline period of sleep. These results are therefore at odds with Hu et al.'s (2006) study, where memory for negative emotional images was improved following a similar period of sleep.

Several other studies have incorporated the R/K procedure under conditions of sleep *deprivation*, which may be more informative for our clinical question. Sterpenich et al. (2007) used a between-subjects TSD design. Recognition testing with the R/K paradigm occurred three days later following recovery of sleep loss. They found a lower overall hit rate to all stimuli in their TSD group, and these subjects showed a deterioration in memory for neutral and positive items but subjective recollection of negative images was left intact and comparable to a sleep control group. They also failed to find a difference in know responses between groups for the different stimuli. Interestingly, they too found response bias to be more conservative overall in their sleep control group, consistent with Hu et al.'s (2006) findings that sleep led to more conservative responding to emotional items. Moreover, this research group report the results of a 6 month retest on the same participants and materials (Sterpenich *et al*., 2009); despite finding several expected main effects of memory type and emotion (e.g. an increase in proportion of know responses since the first test session but a preservation of negative emotional items being assigned remember responses more often), they failed to find any interaction with sleep condition on any of the behavioural data. Notably, in both studies they did reveal important differences in neural activation via fMRI, which we will return to below.

A study by Atienza and Cantero (2008) aimed to shed light on the extent to which subjective remembering and knowing and objective estimates of recollection and familiarity were affected by sleep, valence and arousal. Like Sterpenich et al. (2007) these authors used a TSD paradigm, but instead tested participants one week later to try to eliminate circadian or

alertness influences. Overall, they found stimulus arousal was more important than valence in modulating memory consolidation. In terms of sleep, they found recognition accuracy was significantly poorer in their sleep deprived group, with remember responses and recollection significantly lower but subjective know responses and objective familiarity estimates unaffected by sleep deprivation. It was shown that both subjective and objective recollection indices for neutral items deteriorated following sleep deprivation with no difference found in emotional items. Thus, memory impairment caused by sleep deprivation was independent of valence or arousal and consolidation of neutral memories was affected more by sleep deprivation as in Sterpenich et al. (2007). This study highlights the importance of the first night of sleep on encoding as a full week of recovery was not enough to reverse any behavioural effects.

In summary, behavioural data from the studies that have used the R/K paradigm present conflicting results, but on the whole are not supportive of a beneficial effect of sleep on emotional memory and do not find a detrimental effect of sleep deprivation on emotional memory. Unsurprisingly, overall recognition performance appears more sensitive to the effects of sleep, but this handful of findings collectively imply that restricting sleep would not necessarily have any therapeutic benefit on PTSD development because memory for negative arousing information does not significantly deteriorate with sleep deprivation. The studies by Atienza and Cantero (2008) and Sterpenich et al. (2009) are particularly interesting because they are some of the few studies that examine emotional memory after a delay longer than a day or two. It would be important to assess any effect of sleep deprivation on trauma memory after a number of extended delays.

As we will see below, although explicit emotional memory does not always appear to be influenced by sleep, taking a closer look at the brain and neurophysiological parameters begins to tell a different story.

3.2.1.2 *Associative emotional memory*

Very few of the studies have deviated from the use of single item old/new recognition test formats. The limitations of this are evident, especially when we consider the integrative nature of memory; day-to-day experiences are abound with a variety of sensory-perceptual-conceptual-affective details that give rise to an episodic memory (Williams, Conway, & Cohen, 2007). The development and maintenance of PTSD is dependent on this kind of associative binding, so studies providing an analogue of this natural process are likely to be informative.

The studies in Table 1 conducted by Payne and colleagues have begun to provide some insight into how we selectively encode and consolidate the emotional aspects of complex stimuli, and how sleep affects this process (Payne et al., 2008; Payne & Kensinger, 2011; Payne et al., 2012). These authors have developed a robust paradigm in which participants encode scenes containing negative and neutral foreground objects superimposed on neutral backgrounds (e.g. a car accident on a street vs. a car parked on a street). This design then allows the formulation of a slightly more challenging recognition test in which participants must discriminate between seen/unseen combinations of objects and backgrounds.

In their series of experiments, the authors have controlled for circadian factors by systematically varying the placement of the recognition test and sleep and utilising a large number of participants; their results convincingly demonstrate that recognition performance for negative foreground objects significantly increases following sleep, whereas memory for neutral backgrounds deteriorates. In contrast, a steady decline in memory performance is seen in neutral objects and backgrounds regardless of delay, and these are not enhanced by sleep suggesting that offline consolidation selectively enhances emotional components only.

These findings have particular relevance for PTSD, because re-experiencing symptoms in this disorder often map on to the most emotionally charged "hotspots" of a traumatic event (Grey & Holmes, 2008). Therefore, it can be argued that a clinical aim would be to disrupt the consolidation of these hotspots if possible, such that they are neutralised and unlikely to become pathogenic. Although Payne et al.'s studies did not explicitly investigate sleep deprivation, their results suggest that if a person were to remain awake, the powerful selective enhancing effect of sleep on the emotionally arousing components of an event would not occur. However, this may not mean that the emotionally traumatic experience is not consolidated at all, rather it may be less likely to become such a distinctive feature of the memory trace.

Another research group attempted to assess the effect of sleep on associative emotional memory (Lewis *et al*., 2011). This group have used a task that involves encoding neutral foreground objects presented on neutral or negative background contexts. Memory for the background 'context' is thus the critical measure, rather than a comparison of memory performance for both foreground object and background as in the Payne et al. (2008) task. Lewis et al. (2011) found that sleep, compared to wake, produced a significant increase in context memory in general, but not preferentially for emotional contexts. The authors, in reflecting on their findings state that whereas Payne et al.'s (2008; 2012) data "suggests that memory for emotional details embedded within learned images is enhanced by sleep, our data

show that the associative link between an emotional context and a neutral foreground object is not strengthened in this way."(p.2627). However, the authors discovered compelling functional results via fMRI and make the suggestion that the consolidation aspect of their task was not sensitive enough to be affected by sleep. We discuss task sensitivity later as a general weakness of this research area.

3.2.1.3 *Intentional learning*

It is well established from empirical studies on memory that when information being presented is expected to be of future relevance (e.g. you know will be tested on it), it is better remembered. Thus, instructions during a learning phase to remember the subsequent information provide an explicit cue for the person to recruit additional attentional resources during encoding which may continue to be beneficial during consolidation. On the other hand, emotional salience of incoming information acts as an implicit cue, which the brain automatically 'tags' for future relevance. The extent to which both of these tagging processes occurs clearly has implications for how the memory is later consolidated; it is therefore surprising how few studies retrieved from our search explicitly discuss these issues.

There were two exceptions to this, however. Cunningham et al. (2014) sought to delineate these processes by examining how intentional and incidental encoding would affect the selective enhancement of emotional information during wake and sleep. In a mixed design, the authors used the 12 hour sleep/wake manipulation with two groups of participants in each condition: Half of the participants were informed they would later be tested on the stimuli (expectation group), whereas the other half underwent incidental encoding (incidental group). All participants completed the Payne et al. (2008) scene recognition task described earlier. Their overall behavioural results suggested that the expectation group had better performance for objects compared to backgrounds. They also replicated the emotional memory trade-off effect (memory for emotional objects increases but recognition of background information deteriorates) from previous studies but found the magnitude of this was significantly greater following the expectation that you would be tested. The results also suggested that when the test was unexpected, only the sleep group had better memory performance for negative objects. However, when the test was expected, only the group that had a 12 hour period of daytime waking had a significant increase in memory of negative objects compared to the unexpected group. For the sleep group, no difference was found in the emotional memory trade-off regardless of whether the test was expected or not. This suggests that the offline neurophysiological environment of sleep provides a consolidation benefit which is not additionally enhanced by expecting an upcoming test of the information.

Although this study displays an interesting dissociation between the extent to which expectation and emotional salience of information are consolidated during sleep or wakefulness, it is less helpful from a clinical perspective. This is because a basic manipulation of incidental or intentional encoding is not cogent to understanding how PTSD may develop: people experience traumatic events and it is impossible to passively witness these in a way that is analogous to incidental encoding in the lab because the events have significant meaning. However, whilst victims of a traumatic event may not be able to incidentally encode a memory to reduce its emotionality at a later date, it is well known that people actively try to suppress unwanted aversive memories as a natural way of forcing the trauma out of consciousness. The study by Kuriyama et al. (2013) investigated the interactive effects of memory suppression and sleep on emotional memory consolidation. They used a TSD paradigm and asked participants to watch 10s video clips displaying harmful motor vehicle accidents, as well as neutral clips depicting normal motor vehicle journeys. The authors utilised the directed-forgetting paradigm, whereby participants are instructed to either remember the previously learnt material for later use, or to forget it (Bjork, Bjork and Anderson, 1998). The authors found that sleep deprivation had no effect on event recognition regardless of encoding condition (directed remembering or forgetting) and no difference was found between emotional and neutral item recognition. They also found that sleep deprivation significantly reduced implicit physiological responses in directed-remembering participants, but active suppression of memory led to a greater implicit physiological response generalised to all cues (emotional and neutral) following sleep deprivation. Therefore, sleep deprivation, although not affecting consolidation of the explicit memory, does appear to reduce conditioned fear responses; the results also caution against the combined use of memory suppression and sleep deprivation due to the increase in implicit fear.

3.2.2 *Specific sleep neurophysiology*

Following the discovery of REM sleep in the 1950's (Aserinsky & Kleitman, 1953), growth in our understanding of the specific neurophysiological and neurochemical properties of this sleep stage led to the hypothesis that it may be crucial for emotional memory consolidation. Several of the reviewed studies specifically examined this hypothesis, but mixed results emerge.

3.2.2.1 *Support for REM in emotional memory consolidation*

From the reviewed studies, Wagner et al. (2001) were the first to investigate differences between SWS and REM sleep using the split-night paradigm (Yaroush et al., 1971). They demonstrated superior retention of emotional texts only following late sleep. These authors also demonstrated the strength of this consolidation benefit, as four years later the emotional memory advantage was only seen in their late, REM rich sleep group evidenced by superior forced-choice recognition performance (Wagner et al., 2006). In a similar study, Groch et al. (2013) employed the split-night paradigm but this time with the added benefit of a within-subjects design and the recording of both PSG data during sleep as well as event-related potentials (ERPs) during encoding and recognition. The authors found that REM sleep enhanced the number of high confident correct responses, and only performance in the REM group was associated with increased positivity over the frontal cortex in the critical 300-500ms time window known to be a correlate of recognition memory accuracy. Moreover, in light of this REM related memory benefit, ratings of valence and arousal of images did not change, arguing against the predictions of the SFSR model (Walker, 2009).

Some striking behavioural benefits of REM sleep were further demonstrated in Nishida et al.'s (2009) nap study. They found *d'* for emotional items was significantly increased following sleep but not wake, whereas no difference was found for neutral items within or between groups. Additionally, this performance benefit was found to be related to specific REM parameters but not other sleep stages (REM latency; percentage time spent in REM; and total REM time in minutes), and also correlated with right dominant theta power as shown by EEG analyses – an established neurophysiological marker of REM sleep (Montgomery, Sirota, & Buzsáki, 2008).

Finally, Payne et al. (2012) provided further confirmatory evidence in their now well established object/background discrimination task. These authors showed that memory for negative emotional objects in their scenes increased following sleep, and this performance was correlated with total time spent in REM and percentage of REM sleep.

3.2.2.2 *Studies refuting the role of REM in emotional memory consolidation*

Despite the evidence above that suggests REM is critical for emotional memory consolidation, several studies failed to find such support. Baran et al. (2012) examined the SFSR model (Goldstein & Walker, 2014; Walker, 2009) by measuring changes in valence and arousal for emotional and neutral items as well as item memory in a 12 hour sleep/wake paradigm. Although recognition performance was better following sleep, the authors did not find a

selective increase in emotional items during this period; they also found no relationship between REM sleep time and hits for negative pictures, or for the change in valence and arousal, thus conflicting with Nishida et al.'s (2009) findings. When looking specifically at REM in the latter half of the night though, they found that an increase in REM in the 3rd quarter was associated with a preservation of negativity ratings (i.e. valence). This was not found for REM in the 4th quarter of the night. Thus, although REM was unrelated to measures of memory it was associated with a maintenance of initial emotional ratings of items.

Sawangjit, Siripornpanich and Kotchabhakdi (2013) assessed positive, negative and neutral item memory in a nap paradigm using PSG recording. The behavioural findings showed recognition performance of neutral items increased following a short 90 minute nap period and this was positively correlated with amount of NREM sleep. Unexpectedly, the authors also found that memory for highly arousing emotional items decreased following sleep relative to wake. However, none of the small number of participants in the nap group (*n* = 5) achieved REM sleep during the nap, and the authors suggest the finding may be a result of transient destabilisation processes produced by NREM sleep, which would normally be followed by reconsolidation processes operating during REM.

Finally, Morgenthaler et al. (2014) also failed to find a benefit of sleep on emotional memory, or a relationship between REM and emotional memory performance. They employed a selective REM deprivation paradigm and found that sleep enhanced recognition memory but this was not different between REM deprived and non-REM deprived groups. The authors state that their study is perhaps the most conclusive to date due to increased power from sample size and number of items tested, as well as the advantage of successful REM sleep deprivation (REM deprived group having 5 mins vs. 58 mins in non-REM deprived).

Collectively, the studies have provided evidence that circadian or other confounds such as chronotype (i.e. being a 'morning' or 'evening' type of person) are insufficient to explain an increase in memory performance for emotional, over neutral, texts and images following sleep. The majority of studies demonstrate the importance of REM sleep in this process; some by inference from the split-night paradigm, but others showing what appears to be a dose-dependent relationship. However, the conflicting findings, particularly from Baran et al. (2012) and Morgenthaler et al.'s (2014) studies must not be overlooked and the jury is clearly still out on this issue. There is no perspicuous explanation for the precise role of REM sleep in emotional memory consolidation and affective processing at this stage so it would not be possible to fully support or refute the idea of specifically targeting an individual's REM sleep following exposure to a traumatic event.

The stages of REM and SWS as determined by PSG are considered part of the macro architecture of sleep. However, other work in this field has started to demonstrate the importance of microarchitectural elements such as sleep spindles in the consolidation of memories (Rasch and Born, 2013 for review). A study by Cairney et al. (2014*b*) re-analysed data from the Lewis et al. (2011) context memory study which we included in our selection, and found that memory deterioration and reaction time for neutral contexts were related to sleep spindles occurring over the right frontal cortex. Recent research has also found pharmacological increases in spindle density leading to enhancement of emotional memory (Kaestner et al., 2013). Cairney et al. (2014*b*) speculate that these sleep events may provide differing support to emotional memory consolidation depending on whether the emotional information is central or part of the overall context. The results of this study and similar work provide a more refined view that suggests it may be worth investigating how to intervene with structural elements of sleep to block emotional memory consolidation rather than simply looking at sleep stages.

3.2.3 *Further studies*

Before discussing findings from neuroimaging data, we present results from two studies conducted by Kuriyama et al. (2010; 2011).

Kuriyama et al's. (2010) aim was to test the question underlying the present review. They took into account the interplay between explicit and implicit memory systems and hypothesised that TSD following exposure to aversive events might lead to a decrease in both explicit memory and implicit physiological responses due to the prevention of normal consolidation processes. This was the first use of their motor vehicle accident film paradigm, as described earlier in the context of the Kuriyama et al. (2013) study. Half of their participants were totally sleep deprived and the other half rested normally on the first night of the experiment. At encoding, participants watched 10s films clips of either real motor vehicle accidents or normal car journeys, captured from on-board cameras in Japanese taxis. Implicit responses were recorded and recognition memory was tested on day 1, 3 and 10 using the same old/new task including still images from the films. They found recognition of negative emotional items was increased overall, but there was no difference between normal sleeping and sleep deprived subjects on any of the testing intervals. Their other measures indicated that in the sleep control group, implicit fear recognition generalised to previously seen neutral items, whereas physiological fear responses showed a generalisation to all items, including those previously unseen. This finding was later partially supported in another study (Kuriyama *et al*., 2013).

Thus, the authors highlight how implicit fear generalisation may be accentuated by sleep, meaning sleep deprivation could be a useful therapeutic tool in helping target the prolific generalisation of fear to unconditioned stimuli that occurs in PTSD.

Kuriyama et al. (2011) examined gender differences in event memory and additionally explored the interaction between memory and habitual sleep onset periods (SOPs), or bedtimes. They investigated the hypothesis that aversive events experienced after SOPs tend to be consolidated more than when experienced beforehand. The rationale for the study was that women tend to have higher rates of PTSD than men, but also PTSD is more likely after rape than other events (Kessler, Sonnega, Bromet, Hughes, & Nelson, 1995) and these tend to occur at night after women's normal SOP. Put simply, they were attempting to validate a neurobiological account of the increased incidence of rape-related PTSD in women. Participants watched a two hour 'suspenseful movie' for either three hours before their habitual SOP or one hour after (therefore prolonging wake significantly in this group); recognition memory using old and new still images was tested 15 minutes and 10 hours after watching the film. In men, there were no striking differences in recognition memory between neutral and aversive items between the pre and post-SOP groups, although performance was overall better in the pre-SOP group. For women, recognition accuracy was better in the post-SOP group and aversive images were best recognised; in the female pre-SOP group aversive images showed significantly worse performance. Moreover, no differences were found in performance within or between groups when assessing first and second recognition tests, suggesting circadian or homeostatic factors did not affect episodic memory. The results show that women's encoding of aversive episodes is less sensitive than men before habitual SOPs, but as the night progresses past normal bed time, women's ability to encode aversive experiences increases, and men's remains about the same. These findings are highly specific, and perhaps the most important message of the present review is to highlight potential gender differences in encoding and consolidation of stressful experiences. Few of the other studies have considered gender differences and this is clearly a variable of importance.

3.2.4 *Beyond behaviour: neuroimaging data*

The behavioural data obtained from the selected studies have provided somewhat conflicting results, with a number of null findings. However, several of these studies also implemented fMRI analyses which provide an understanding of the relationship between sleep and emotional memory consolidation at a functional level.

Sterpenich et al.'s studies (2007; 2009), although failing to find any behavioural difference on negative emotional items between rested and sleep deprived participants, found different patterns of neural activation. First, their sleep group showed greater activation in the medial prefrontal cortex (MPFC) and hippocampus during successful recollection of all items as compared to the TSD group. Moreover, for negative items they found greater activation in the amygdala for the TSD group, whereas the sleep control group displayed a more distributed hippocampo-neocortical pattern. In their 6 month follow-up of the same participants, they found substantially less activation in the hippocampus but activity was now distributed throughout the amygdala, ventromedial prefrontal cortex (VMPFC) and middle occipital cortex for recollection of negative items in their sleep control group. Conversely, this change in network activation was not observed in the sleep deprived group.

Another study in which functional results overshadowed the absence of behavioural effects comes from Lewis et al. (2011). In their context memory paradigm they found an interaction between valence and retention type (sleep/wake) such that the sleep group displayed a significant increase in activation for responses to negative contexts in several brain regions; the strongest of these was in right anterior parahippocampus, as well as left amygdala then VMPFC, posterior cingulate and precuneus. Furthermore, connectivity analyses showed greater functional coupling between parahippocampal and amygdala regions in the sleep group following successful recognition.

We mentioned previously that Cairney et al. (2014) did not find an impairment in recollection of negative images following sleep deprivation; however, their combined neurophysiological and functional data expand upon this picture. They found SWS predicted better memory performance for remote negative images and there was a corresponding reduction in right amygdala activity. REM on the other hand was related to increased connectivity between hippocampal-neocortical areas for recollection of remote negative items. Thus, the results are supportive of a sequential view of emotional memory consolidation in which these two sleep stages work in concert.

Payne and Kensinger (2011) utilised an object/scene recognition task to investigate functional differences following sleep and wakefulness. For their waking group, they found widespread activity in the lateral prefrontal and parietal cortices as well as the medial temporal lobe (MTL) which corresponded more strongly to successful retrieval of negative items as compared to the sleep group. On the other hand, the sleep group showed a more distinguished network involving strong activation during retrieval of negative items in the left amygdala, VMPFC and

cingulate gyrus. Moreover, after sleep the amygdala had a stronger influence on the hippocampus and VMPFC than it did after wake.

What we can draw from the above findings is that even in the absence of differences in explicit behavioural measures (i.e. recognition performance) between sleep groups, there is consistent functional evidence suggesting that emotionally charged declarative information is strengthened by sleep-dependent consolidation processes. The candidate process for this is systems consolidation (Stickgold & Walker, 2007), in which initially labile hippocampal-based memory traces are redistributed to more neocortical areas via recruitment of an emotional memory network involving the amygdala (McGaugh, 2004). This ongoing process of consolidation allows memories to be easily reactivated, or consciously recalled in the future. Thus, although the extent of sleep deprivation on explicit emotional memory is still up for debate, these neuroimaging findings suggest that it would inhibit normal neural consolidation processes. It is unknown, however, what this would look like following the encoding of a much more inflated emotional experience such as those that typically lead to PTSD.

4. *Discussion*

This systematic review aimed to extract studies from the literature that would help answer an interesting question related to the early development of PTSD symptomatology: can restricting sleep following exposure to a traumatic event have a prophylactic effect by blocking or impairing consolidation of the emotional memory? This question is motivated principally by the mnemonic view of PTSD (Rubin et al., 2008), which propounds that symptoms of the disorder only develop if an episodic memory of the traumatic event(s) exists in the brain. Therefore a prediction of the model is that in the absence of a memory, symptoms should not develop; interfering with post-event consolidation mechanisms is thus a potential way of achieving this. A number of recent articles have provided a narrative synthesis of findings regarding the role of sleep-dependent emotional memory consolidation (Cunningham, Pardilla-delgado, Alger, & Payne, 2014; Cunningham, Crowell, et al., 2014; Goldstein & Walker, 2014; Holland & Lewis, 2007b; Walker, 2009, 2010), but to our knowledge ours is the first to directly tackle the above question.

Perhaps unsurprisingly given the relative infancy of the literature, our review suggests there is currently not enough evidence to make a well-founded clinical recommendation to deprive people of sleep after trauma. In order to further examine the utility of this idea, we suggest

that research incorporate existing knowledge regarding our understanding of the development of PTSD. Below we identify some of the limitations with this area of research in answering our clinical question and make recommendations for further work.

4.1 *Individual characteristics and generalizability*

One of the inherent problems with this area is the extent to which emotional memories in the laboratory, which are often simply derived from briefly presented still images, can be likened to those encountered in the real-world. Compounding this problem is the fact that like much research, the existing data are based on samples consisting of high-functioning young undergraduate students (see Henrich, Heine, & Norenzayan, 2010, for a general criticism of this method). It is well-known that a number of pre-existing individual factors contribute to the likelihood of PTSD development (Ozer, Best, Lipsey, & Weiss, 2003). For example, differences in gender, IQ, verbal memory ability, disturbed sleep and biological markers are known to predispose certain people to developing the disorder (Breslau, Chen, & Luo, 2013; Brewin, 2011; Kessler et al., 1995; Sherin & Nemeroff, 2011; van Liempt, 2012; Wild & Gur, 2008). Some of these factors are controlled to a certain extent in the reviewed studies, but a striking omission is the consideration of gender differences throughout, albeit with some exceptions (e.g. Kuriyama, Mishima, Soshi, Honma, & Kim, 2011). Simply assessing consolidation processes on emotional memory following acquisition, without taking into account these pre-existing differences is unlikely to translate into clinically meaningful conclusions.

4.2 *Processes operating at encoding*

A recent article by Conte and Ficca (2013) addresses a number of shortcomings with the sleep-consolidation literature: one of the limitations they discuss is the general failure of studies' designs to be informed by well-established findings from the cognitive psychology literature. For example, task difficulty, motivation, attention, insight, intelligence, individual learning ability and intention-to-learn are all variables that are known to exert robust influences on memory performance yet these factors have received little attention in the reviewed studies (though see Cunningham, Chambers, et al., 2014, and Kuriyama, Honma, Yoshiike, & Kim, 2013). The fact there are discrepancies in behavioural findings between the studies reported here despite many of them using the same stimuli from the IAPS dataset and the same type of student sample suggests that some of these factors are at play. Moreover, when only examining emotional memory for a series still images, it is unlikely that the same sort of cognitive-emotional processes are operating as they would in the case of real-life trauma. Such cognitive processes occurring during trauma are a core part of cognitive conceptualisations of how the disorder develops (Ehlers & Clark, 2000), and it has been shown that differences in

these peri-traumatic processes are highly important in predicting later symptom development (Ozer et al., 2003). Obtaining subjective ratings of emotional reactivity is a method used in some of the reviewed studies – for example by obtaining valence and arousal ratings of images. However, investigating how higher level cognitive-emotional processes during encoding interact with later sleep-consolidation processes will be important.

4.3 *Retrieval processes*

In real-life, events unfold over extended periods of time and are situated in a personal context that provides a narrative for the person. When we think about the processes involved in the retrieval of such events, it is often a vivid, recollective experience that characterises emotional memories (LaBar & Cabeza, 2006). Only a handful of the studies reviewed consider potential behavioural differences in retrieval processes, apart from those where the remember/know paradigm was utilised to estimate subjective and objective recollection and familiarity (Atienza & Cantero, 2008; Cairney, Durrant, Power, & Lewis, 2014; Hu, Stylos-Allan, & Walker, 2006; Sterpenich et al., 2007, 2009). Even though some interesting findings emerged from these studies regarding the role of recollection, they are all derived from recognition memory paradigms. This format does not tap into the strategic, effortful recollection process governed by top-down executive control that characterises recall (Tomita, Ohbayashi, Nakahara, Hasegawa, & Miyashita, 1999).

We propose that a priority for future research will be to examine recall as well as recognition memory. Importantly, this should not simply be confined to assessing voluntary recall. Involuntary memories of an aversive event, also known as intrusions or flashbacks, are a hallmark feature of PTSD. If we are to understand whether sleep deprivation has a therapeutic effect on PTSD symptom development, explicit voluntary memory of the event is only part of the story. Whilst the mnemonic view of PTSD makes a straightforward prediction that availability of the declarative memory affects symptom development, there is currently debate in the literature regarding the extent to which voluntary and involuntary forms of memory for an emotional event are linked (see Berntsen & Rubin, 2014, and Brewin, 2014). Further work that provides a measure of both forms of memory, incorporated with sleep manipulations, will help clarify this theoretical issue. The trauma-film paradigm will be useful for this purpose, as it is considered a robust and valuable way to investigate the mechanisms involved in the development of PTSD (Ehring, Kleim, & Ehlers, 2011; Holmes & Bourne, 2008). In this paradigm, peri-traumatic cognitive processes can be manipulated or measured whilst a participant watches an aversive film, and voluntary memories can be measured by recall or

recognition and involuntary memories can be recorded via diaries in the subsequent days following exposure. This paradigm therefore overcomes several of the problems outlined with the methods adopted in existing studies.

Out of the studies we present here, only Kuriyama et al.'s (2010; 2011; 2013) programme of research used films during encoding. This is surprising given the body of literature that has utilised the trauma-film paradigm to investigate analogue trauma. Despite their use of aversive films, the Kuriyama et al. studies assessed recognition memory for still images of the clips and no compelling sleep-related behavioural differences in emotional over neutral stimuli were found. Due to the lack of studies using this methodology, we highlight a need to continue investigating this area using modified experimental tasks that are perhaps more effective in inducing analogue distress and emotional reactivity. The existing literature using the trauma-film paradigm could easily be extended for this purpose, or alternatively, the use of virtual reality (VR) environments may prove a further effective means in the future. For example, VR is already used in exposure therapy for PTSD (see Gerardi, Cukor, Difede, Rizzo, & Rothbaum, 2010, for a review) and evidence has shown that it can be an effective analogue to trauma, inducing distress in healthy volunteers (Josman, Reisberg, Weiss, Garcia-Palacios, & Hoffman, 2008). Creating such an immersive environment is obviously subject to ethical concerns regarding the extent to which subjects are distressed. However, using materials like this and measuring various forms of memory retrieval will simulate the kinds of processes involved in real-life trauma better.

4.4 *Proposed research framework*

In Figure 2 we present an overview of how the stages of memory can be used as a guide for directing further research. This overview includes the elements of studies already published, but also some further areas in which to extend the field. As we have alluded to above, the principal additions to the literature we suggest come in the form of acknowledging individual differences to susceptibility of PTSD symptom development; experimenting with alternative, more ecologically valid encoding materials such as films; assessing cognitive processes operating during encoding; and further measurement and comparison of alternative voluntary and involuntary retrieval mechanisms. These manipulations must all be integrated, as far as possible, with the existing paradigms reviewed here that have collectively tackled some of the issues around consolidation and circadian influences. The gold standard recording method of PSG will continue to have pervasive use, but as Conte and Ficca (2013) outline, the tendency to focus only on the macroarchitectural aspects of sleep provides only a basic view of how offline consolidation works. Future work may therefore wish to focus on the microarchitecture of sleep, examining eye movements during REM, or sleep spindles for example. Naturalistic

designs will also need to be employed, or perhaps combinations of PSG with time spent in the subject's normal environment. This will be particularly important if examining the time course of consolidation and memory (both voluntary and involuntary) over extended periods of time. It is well known that sleep is disordered in PTSD patients in the nights following exposure to trauma (van Liempt, 2012), therefore the focus of enquiry cannot solely be on the first night following exposure to aversive events. This risks neglecting the effect of subsequent sleep or wake on the reconsolidation of emotional memories. Reconsolidation refers to the process whereby initially consolidation memories can be reactivated and made labile once again, allowing further alterations to the memory trace. This reactivation can occur during sleep, temporarily destabilising memories, or during wake following retrieval. We explicitly include reconsolidation in Figure 2.

The issues we outline here are not meant to be exhaustive, rather they are intended to clarify ways of developing this research in order to begin thinking about clinical implications as well as expanding theoretical understanding. One gap we acknowledge is that we have thus far only focused on declarative emotional memory. To drive forward clinical practice, a synthesis of findings from different streams of research will be necessary. For example, results of studies investigating non-declarative memory will be informative as the implicit memory system is crucial to understanding PTSD due to the putative role fear conditioning has in the development and maintenance of the disorder. At the time of a trauma, stress and hormonal responses lead to fear learning via Pavlovian conditioning initially in the amygdala, with later recruitment of the hippocampus (LaBar & Cabeza, 2006). Subsequently, learned fear from the conditioned stimulus (i.e. the target traumatic event) is difficult to extinguish and generalises to other benign, previously unconditioned stimuli potentially due to impaired sleep consolidation processes (Milad et al., 2009). It is precisely this 'fear network' that is the target of exposure-based cognitive therapies (e.g. Foa & Kozak, 1986). Several studies have been conducted in recent years examining the effect of sleep on non-declarative memory consolidation using classical conditioning paradigms (Menz et al., 2013; Pace-Schott et al., 2009, 2013, 2014; Spoormaker et al., 2010; 2012). It is beyond the scope of our review to discuss these here, but notably, there has been some support that REM sleep is correlated with consolidation of fear memories, leading the authors to conclude that further work examining the therapeutic value of REM sleep deprivation would be interesting to investigate (Menz et al., 2013). Further research in this area will complement the findings of declarative memory studies.

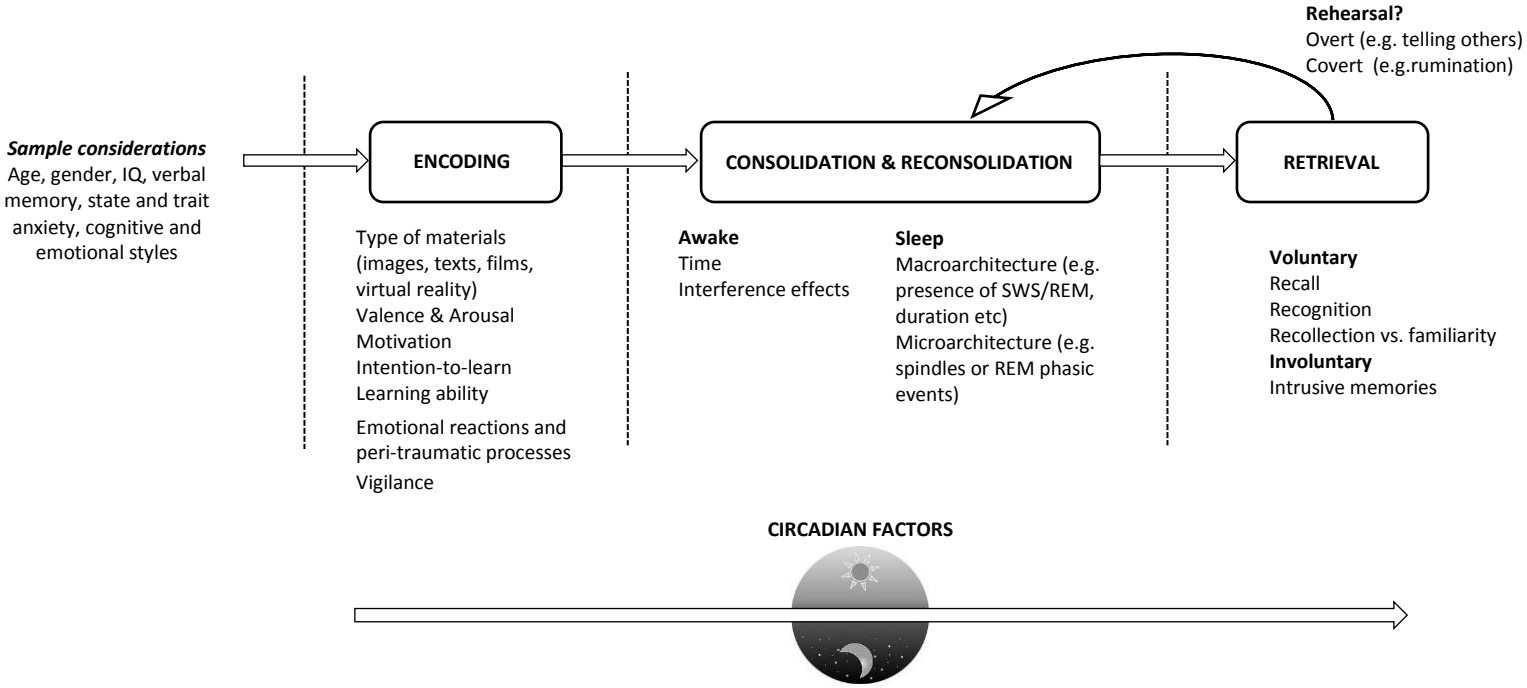

Figure 2. Factors to consider in future work examining sleep-dependent emotional memory consolidation.

A further parallel area of investigation has been to specifically focus on sleep's role in habituating both explicit and implicit emotional reactivity (Cunningham, Crowell, et al., 2014; Lara-Carrasco, Nielsen, Solomonova, Levrier, & Popova, 2009; Rosales-Lagarde et al., 2012; van der Helm et al., 2011; U. Wagner, 2002; Werner, Schabus, Blechert, Kolodyazhniy, & Wilhelm, 2015). As with the memory literature, these studies appear to display discrepant findings. For example, some have found evidence to suggest REM sleep potentiates, or increases affective reactivity to previously seen stimuli (Lara-Carrasco et al., 2009; Wagner et al., 2002) and others have found that sleep depotentiates, or reduces emotional reactivity to stimuli via subjective ratings, physiological measures and at a functional level (Cunningham, Crowell, et al., 2014; Pace-Schott et al., 2011; Rosales-Lagarde et al., 2012; van der Helm et al., 2011; Werner et al., 2015).

4.5 *Conclusion*

In sum, this review has focused on one particular area of memory. There are a number of different approaches that have recently been applied to understanding sleep-dependent emotional memory consolidation mechanisms. Although we provide a guide for the development of future declarative memory studies, in order to further delineate the potential therapeutic benefit of sleep deprivation on development of PTSD a combination of the methods already being used is likely to be beneficial. There is currently divergence in findings in all of the above areas of research, meaning there is room for much more investigation. In our view, a key priority is to enhance the ecological validity of studies as far as possible so that this work can eventually be safely, and informatively trialled with real-life trauma survivors. Currently, researchers have tended to consider which of two options is better: disrupting initial sleep-dependent consolidation processes so the explicit memory itself is weakened (e.g. via REM sleep deprivation); or encouraging healthy REM sleep so that the person is able to remove the 'affective blanket' from the memory (Goldstein & Walker, 2014; Walker & van der Helm, 2009). Ultimately, however, a combination of the two methods may be most effective.

5. *References*

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EMPIRICAL PROJECT

The sleeping brain and emotional memory consolidation: An analogue investigation into the role of sleep on intrusive memory development in PTSD.

Main supervisor: Dr Jennifer Wild

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Empirical Project

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Abstract

Evidence points to a role of rapid eye movement (REM) sleep in emotional memory consolidation, suggesting that sleep disruption may impair the consolidation of emotional memories, which could influence the development post-traumatic stress disorder (PTSD). Despite many studies examining explicit voluntary memory, the impact of sleep deprivation on intrusive memory development has yet to be examined. The present study employed the trauma-film paradigm to investigate the effect of REM deprivation on involuntary and voluntary memory. A REM deprived group (REM-D) and sleep control (SC) group watched aversive films and recorded intrusions over one week and were then given a visual recognition task and verbal generative recognition task. Findings revealed no differences in number of intrusive memories recorded over the week between the groups, but the level of distress associated with these tended to be higher in the REM-D group. Visual recognition performance was equivalent after one week, but performance on the task requiring recall displayed a significant difference with REM-D participants performing more poorly. Our results argue against recommending therapeutic sleep deprivation for individuals exposed to trauma due to the lack of effect on intrusive memories, and the observed effect of REM sleep deprivation on memory recall and distress. REM deprivation highlights a dissociation in different routes to memory retrieval, lending support to the proposal that intrusions are stored as more perceptual-based memories and perhaps undergo a consolidation process divergent to that of explicit emotional memories.

1. *Introduction*

Post-traumatic stress disorder (PTSD) is a chronic, disabling psychological condition that arises in a small number of people following exposure to highly stressful events (American Psychiatric Association, 2013). One of the hallmark symptoms of the disorder is the emergence of spontaneous, intrusive memories of scenes or images from specific parts of the traumatic incident; these cause great distress to the experient due to their involuntary nature and tendency to be laden with emotion as if re-experiencing the 'hotspots' of the event (Grey & Holmes, 2008). Intrusive memories, or 'flashbacks', are increasingly considered to be a core part of the disorder in diagnostic classification systems (e.g. Maercker et al., 2013) and some suggest that they are the nucleus of the problem in PTSD, serving to maintain the other symptoms (Foa, Zinbarg, & Rothbaum, 1992; Michael, Ehlers, Halligan, & Clark, 2005). Understanding the mechanisms involved in the aetiology of flashbacks thus has clinical relevance because of the potential to intervene early after trauma to prevent the development of intrusive memories and linked PTSD symptoms. Moreover, the search for effective early interventions is a priority given that current psychological treatments for PTSD are effective but tend to be delivered years after someone has suffered with the disorder (P. S. Wang et al., 2005). The current study examines the contribution of sleep to the development of intrusive memories, which may inform future early interventions or recommendations.

Given the ethical constraints of researching trauma in the laboratory, a robust method used to investigate both involuntary (i.e. flashbacks) and voluntary (recall and recognition) forms of aversive memory has been the trauma-film paradigm, in which participants are exposed to one or several distressing films that depict content in line with the DSM criteria for a traumatic stressor (Holmes & Bourne, 2008; Horowitz, 1969). Following exposure to analogue trauma, participants are typically asked to record in a diary the occurrence and qualitative characteristics of intrusive memories for scenes of the films that arise in the following week, and later their explicit memory can be tested upon return to the laboratory. Because cognitive processes during (termed 'peri-traumatic') and after the trauma can be manipulated and measured, this method has been instrumental in testing out the tenets of cognitive models of PTSD (Brewin, Dalgleish, & Joseph, 1996; Brewin, Gregory, Lipton, & Burgess, 2010; Brewin, 2001; Ehlers & Clark, 2000).

For example, the dual-representation theory (Brewin *et al*., 2010) asserts that memories of traumatic events are encoded by two different memory stores: contextually bound representations (C-reps) that are hippocampally driven support deliberate recall of episodic details of an event and allow one to mentally reconstruct the event upon retrieval; in contrast,

lower level perceptual processing of an event leads to the encoding of sensory representations (S-reps) including visuospatial elements that are formed with little conscious processing, and also represent the autonomic markers of affective values (i.e. emotions such as a fear, disgust). These two types of representation normally interact, but at times of extreme stress, reduced hippocampal function and increased amygdala functioning lead to a pathological encoding whereby stronger S-reps are created, with weaker C-reps, and fewer connections between them (Brewin et al., 2010). Flashbacks are the result of S-reps, and are easily triggered in a bottom-up fashion by environmental or internal (bodily states or emotions) stimuli bearing resemblance to elements of the initial experience. The lack of C-rep in this process leads to a perception of re-experiencing the event.

Drawing on the hypothesised nature of S-reps in flashback formation, Holmes, James, Coode-Bate, and Deeprose (2009) explored a potential early intervention technique that involved administering a visuospatial task to participants following exposure to analogue trauma. They reasoned that engaging in a visuospatial task immediately after exposure would compete for resources in visual working memory, meaning a just-encoded sensory-perceptual representation would be vulnerable to interference. Findings revealed that participants who played a visual based computer game 30 mins after watching trauma films reported fewer flashbacks in the subsequent week, but recognition memory performance, presumed to rely more on medial temporal lobe processing or C-reps, was statistically equivalent between the groups. Moreover, as reviewed by Brewin (2014), several other studies have demonstrated that engaging in a visuospatial task reduces the number of intrusive memories over a one-week period.

These studies demonstrate examples of how interfering with the consolidation of an aversive memory during or directly following encoding can have an impact on later retrieval processes – specifically, the involuntary, sensory-bound retrieval of flashbacks. Similarly, the impact of reducing the availability of the explicit memory of an aversive event has been outlined in a mnemonic model of PTSD proposed by Rubin, Berntsen, & Johansen, (2008). In this model, PTSD develops and is maintained by the declarative memory of a traumatic event. Rubin et al. suggest two straightforward predictions based on this assertion: that increasing the availability of the memory will increase PTSD symptoms; and conversely, decreasing the availability of the memory will decrease symptoms. In support of the latter, some studies suggest that patients with organic amnesia for a highly stressful event following traumatic brain injury (TBI) tend to have lower rates of PTSD (Gil, Caspi, Ben-Ari, & Klein, 2006; Harvey, Brewin, Jones, & Kopelman, 2003). Moreover, recent studies have shown some evidence that certain pharmacological compounds administered within a critical 6 hour period following trauma

exposure can be effective in reducing PTSD symptoms (Amos, Stein, & Ipser, 2014); although the mechanism of action is not entirely clear, this effect is thought to be responsible in part due to the suppression of emotional memory consolidation in this post-trauma epoch.

These streams of research thus provide novel insights into potential ways to intervene with people who are exposed to trauma. A third method has also gained interest in recent years following development of our understanding in how and when emotional memories undergo most of their consolidation: during sleep. Although memories remain labile and susceptible to change in the waking hours immediately following their instatement (Walker, Brakefield, Hobson, & Stickgold, 2003), a number of studies have recently examined the extent to which emotional and neutral memories are consolidated during offline periods of sleep (Walker, 2010). This growing literature increasingly demonstrates that the environment of sleep acts to selectively strengthen emotional memories over neutral ones due to the evolutionary advantage they confer. Furthermore, this strengthening is believed to occur specifically during rapid eye movement (REM) sleep, due to several unique neurochemical, neurobiological and electrophysiological processes occurring during this period (Diekelmann, Wilhelm, & Born, 2009; Goldstein & Walker, 2014; Walker & van der Helm, 2009). As well as its involvement in emotional memory consolidation, efficient REM sleep is also thought to be crucial for healthy emotional processing more generally, with lack of REM being related to enhanced emotional reactivity to previously viewed stimuli (Cunningham, Pardilla-delgado, Alger, & Payne, 2014; Rosales-Lagarde et al., 2012).

Because of sleep's role in consolidation, a discussion has recently emerged regarding the potential role of sleep deprivation as a natural way of preventing the consolidation of aversive memories, and thus the development of PTSD symptoms (Goldstein & Walker, 2014; Holland & Lewis, 2007; Wagner, Hallschmid, Rasch, & Born, 2006). This contention was recently reviewed with reference to empirical evidence derived from declarative memory studies in the literature (Illman & Wild, *this volume*). On a behavioural level, the evidence is mixed as some studies find that emotional memory strength is improved by sleep compared to neutral memories, whereas other studies find no improvement in performance, or at least not a preferential benefit for emotional memory following sleep. Moreover, whereas properties of REM sleep, as compared to slow-wave sleep (SWS) were found to enhance emotional memories in some studies (Baran, Pace-Schott, Ericson, & Spencer, 2012; Groch, Wilhelm, Diekelmann, & Born, 2013; Nishida, Pearsall, Buckner, & Walker, 2009; Wagner, Gais, Born, & Lu, 2001; Wagner, Hallschmid, Rasch, & Born, 2006), others did not find this benefit (Morgenthaler et al., 2014).

Many other insights have emerged from this literature, such as identification of functional networks responsible for emotional memory consolidation in the absence of performance differences on behavioural memory tasks (Sterpenich et al., 2007, 2009). Since emotional memory is primarily operationalised as recognition performance on old/new single item tests utilising the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005), there is danger that extrapolating findings from this research will simplify memory and conflate all types of retrieval when what is really being studied is perhaps best termed emotional recognition memory. Thus, what is yet to be established is the extent to which sleep deprivation affects different forms of emotional memory retrieval. Given that PTSD involves an interaction between involuntary and voluntary forms of memory, it is necessary to establish how the blocking of sleep consolidation processes might affect each of these.

In the current study we used the trauma-film paradigm to this end: we compared a normally rested group of healthy adults with a group deprived of REM sleep and obtained measures of involuntary and voluntary memory over the course of the following week. Voluntary retrieval was measured using a standard old/new single item visual recognition test, thus providing an index of medial temporal lobe function (Eichenbaum, Yonelinas, & Ranganath, 2007). Additionally, because of the overreliance on this method in previous research, we also incorporated a task that would draw more on effortful and strategic frontal lobe mediated recall processes. We call this a generative recognition task, described in the Methods section below.

Our experimental design essentially allowed us to test the question of whether interfering with memory consolidation operating during REM sleep will have a uniform, or variable effect on three different routes to memory retrieval. This analysis is important given that the clinical utility of therapeutic sleep deprivation would only be demonstrated if both voluntary and perhaps more importantly, involuntary forms of traumatic memory are reduced. Although there are mixed findings in the literature regarding the role of REM sleep in emotional declarative memory consolidation, we made the tentative prediction that explicit memory on both our tasks would indeed be impaired following REM deprivation. This is because the trauma-film paradigm has not yet been fully investigated, and a previous inability to detect sleep deprivation-related emotional memory impairment may be explained by the use of still images in prior research. Aversive films which incorporate a narrative are likely to have a more pronounced emotional reaction in participants, potentially making these stimuli more sensitive to detecting sleep consolidation processes.

With respect to intrusive memories, we similarly predicted that retrieval would be impaired following REM deprivation (i.e. fewer intrusions). This prediction was based on accumulating evidence that has emphasised the similarities between voluntary and involuntary memory of emotional events (Hall & Berntsen, 2008; Staugaard & Berntsen, 2014) and furthermore the fact that the neural signature involved during encoding of scenes in trauma-films that later flashback recruit some of the brain structures involved in REM-dependent emotional processing, such as the amygdala and areas responsible for explicit memory (Bourne, Mackay, & Holmes, 2013; Clark et al., 2014). Therefore, whilst dual-representation theory emphasises the differences between the encoding of voluntary and involuntary memories, we predicted a similar impairment on both from sleep deprivation because they are each heavily driven by the recruitment of emotional networks that may be affected by blocking REM sleep.

Finally, we also recorded the subjective distress associated with intrusive memories, which provides a measure of emotional reactivity to the previously encoded, and now involuntarily re-experienced stimuli. Based on findings that emotional reactivity is enhanced following REM deprivation, we predicted that subjective distress levels would be higher in our sleep deprived group compared to normally rested participants in the subsequent waking period.

2. *Method*

2.1 *Power analysis and sample size*

A power analysis was conducted using Cohen's power primer to estimate the sample size required for the present study. In order to estimate effect sizes, we used the results from a study by Sadeh, Dan, and Bar-Haim (2011) which investigated the effect of restricted sleep on sustained attention; these authors found a large effect of impairment on a test of sustained attention following sleep restricted to 4 hours or less compared to a normal night of sleep. Since attention is highly correlated with memory, we would expect a similarly large effect related to sleep restriction and the different forms of memory under investigation presently. Thus, setting α at 0.05 for a two-sided test with power set at 80% and consulting Cohen (1992) indicated a sample size of 52 (26 per group).

2.2 *Participants*

Fifty two participants were recruited in return for £15 cash reimbursement (16 Males; *Mean age* = 22.15, *sd* = 3.95). Participants were drawn from King's College London (KCL) participant recruitment circulars and primarily included undergraduate students. The KCL ethics review

board approved all study procedures (*ref: PNM1314-57,* see Appendix 1) and written consent was obtained prior to completion of the study. Participants were initially screened via email questionnaire to meet the following criteria: no extensive medical training involving traumatic experiences; no prior participation in PTSD studies; not currently experiencing symptoms of anxiety or depression and no history of PTSD; no history of neurological problems or head injury; not currently taking any medication that may affect cognitive function or sleep; non-smoker; currently maintaining a regular sleep cycle of approximately 7-9 hours per night between the hours of 10pm-10am; and willing to comply with study instructions. Participants were all fluent English speakers and had normal or corrected-to-normal vision. They were asked to refrain from caffeine and alcohol for 48 hours prior to the study and for at least the first two days of the protocol, after which they were instructed to avoid excessive amounts due to potential effect on sleep.

2.3 *Materials*

2.3.1 *Measures*

Participants completed a number of questionnaire measures during the initial testing session, as well as over the course of the study. The sleep diary and measures completed in the initial session acted as screening tools to exclude participants that had clinically significant levels of mental health problems or showed an irregular sleep pattern, as well as to match the groups according to demographic factors, PTSD symptoms, depression, anxiety and vigilance (all unpublished questionnaire materials can be found in Appendix 2).

2.3.2 *PTSD, depression and anxiety measures*

2.3.2.1 *Trauma screener (unpublished)*

The trauma screener is a self-report checklist of traumatic events based on that found in the Clinician-Administered Post-Traumatic Scale (CAPS; Blake et al., 1990). It was administered to identify the participant's most stressful life event for them to reference when completing the baseline IES-R; if no events were recorded then the IES-R was not completed and a score of 0 was given. The trauma screener has been used in previous studies (e.g. Ehlers et al., 1998). Participants are asked to answer 'yes' or 'no' to a 22-item checklist of traumatic events (e.g. serious traffic accidents, sexual assault, imprisonment), and given the option to record any

other type of event they consider traumatic that is not listed. If they answer 'yes', they are further asked to indicate whether they experienced distressing, unwanted memories of the event.

2.3.2.2 *Impact of Events Scale-Revised (IES-R; Weiss & Marmar, 1996)*

The IES-R is a 22-item measure of PTSD symptom severity, used frequently in both research and clinical settings. Participants rate the distress caused by their symptoms from 0 ('not at all') to 4 ('extremely') over the last seven days with respect to the traumatic event that they have experienced. Higher scores indicate greater PTSD symptom severity, with a total score of 88. In the current study the trauma screener was used to identify the index trauma for completion of the IES-R at baseline and a clinical cut-off of 33 was used as recommended by Creamer, Bell and Failla (2003).

The IES-R is composed of three subscales: intrusion, avoidance and hyper-arousal. The IES-R has been shown to have high internal consistency for the total scale and the three subscales (Creamer et al., 2003; Weiss & Marmar, 1996). Good test-retest reliability has been demonstrated over a six-month period for the total score (87-.94), intrusion scale (.89), avoidance scale (.79), and hyper-arousal (.82) (Sundin, 2002; Weiss & Marmar, 1996). The scale also has acceptable discriminate validity and high correlations between IES-R scores and other measures of PTSD symptomatology, anxiety and depression have demonstrated good concurrent validity (J. G. Beck et al., 2008).

2.3.2.3 *Beck Depression Inventory-II (BDI-II; A. T. Beck, Steer, & Brown, 1996)*

The BDI-II is a 21 item self-report instrument that taps into psychological and somatic manifestations of a major depressive episode as operationalised by the DSM-IV (APA, 1994). It is used in both research and clinical settings. Items are scored between 0-3 (max score = 63) with higher scores indicating greater severity of depression. The original standardisation sample of non-clinical participants indicated a cut-off of 14 for minor depression, which was the score used in the present study to exclude participants (none of which reached this score). A recent review by Wang and Gorenstein (2013) summarised all studies to-date that have assessed the psychometric properties of the BDI-II and concluded that the scale has high reliability, good ability to discriminate depressed and non-depressed people, and good concurrent, content and structural validity.

2.3.2.4 *Spielberger State-Trait Anxiety Inventory (STAI; Spielberger, Gorssuch, Lushene, Vagg, & Jacobs, 1983)*

The STAI is a 40-item instrument split into two forms; the Trait inventory (20 items) measures anxiety as a personal characteristic or tendency, whereas the State inventory (20 items) measures anxiety in response to a given situation. This difference is determined by asking participants to respond to similar statements (e.g. I feel nervous and restless) differently across the two forms; the Trait form probes how participants generally feel, and the State form asks how they feel at this moment in time. Items range from 0 (Not at all) to 3 (Very much so) (max score = 60 on each scale), with higher scores indicating greater anxiety. The STAI is commonly used in research and clinical practice, with internal consistency coefficients ranging from .86 to .95; test-retest reliability coefficients ranging from .65 to .86 (Spielberger et al., 1983); and good construct and concurrent validity also being demonstrated in other studies (see Spielberger, 2010).

2.3.3 *Sleep measures*

2.3.3.1 *Sleep diary (unpublished)*

A sleep diary was given to participants and completed for the week before, and throughout the study. Participants were instructed to fill out information each day regarding their bedtime; how long they took to fall asleep; number of awakenings; estimated time awake during night; wake-up time; time out of bed; and subjective rating of sleep quality ranging from 1 (Very poor) to 5 (Very good). This type of sleep diary is used widely in sleep research and it has been shown that participants subjective recordings are a reliable estimate compared to objective data collected from polysomnography (Rogers, Caruso, & Aldrich, 1993).

2.3.3.2 *Insomnia Severity Index (ISI; Bastien, Vallières, & Morin, 2001)*

The ISI is a 7-item self-report questionnaire that assesses the nature, severity, and impact of insomnia. A 5-point Likert scale is used to rate each item with a score of 0 indicating no problem, up to 4 indicating a very severe problem (max score = 28). The ISI evaluates: severity of sleep onset, sleep maintenance, and early morning awakening problems, sleep dissatisfaction, interference of sleep difficulties with daytime functioning, noticeability of sleep problems by others, and distress caused by the sleep difficulties. Scores in the range of 8-14 indicate sub-threshold insomnia (Morin, Belleville, Bélanger, & Ivers, 2011) and participants in the current study were excluded if they scored higher than this level (none were excluded).

The ISI has good internal consistency ranging from .90 to .91; adequate discriminatory capacity for 5/7 of the items; and good convergent validity (Morin et al., 2011).

2.3.3.3 *Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973)*

The SSS is a self-rating scale used to measure sleepiness by asking participants to indicate their current level of vigilance based on 7 options ranging from 1 (Feeling active, vital, alert, or wide awake) to 7 (No longer fighting sleep, sleep onset soon; having dream-like thoughts) with items in-between representing increasing levels of sleepiness. It is one of the most widely used subjective sleepiness instruments, and studies suggest it is sensitive in revealing sleepiness following sleep deprivation (e.g. Herscovitch & Broughton, 1981). Although the discriminant validity of the measure has been challenged (see Shahid, Shen, & Shapiro, 2010), it was only used in the present study to ensure that participants in each group had a comparable level of alertness at the baseline testing session, and was thus not used as a tool to highlight potential sleep disordered subjects.

2.3.4 *Emotional reactivity - Mood and arousal visual analogue scales (unpublished)*

Participants were presented with two visual analogue scales to indicate their current mood, ranging from 0 (Extremely negative) to 100 (Extremely positive); and their current level of arousal by asking how activated they currently felt, ranging from 0 (Sleepy) to 100 (Activated – heart beating fast, sweaty). The scales were presented before watching the films and directly after, in order to gain a measure of emotional reactivity. These were recorded primarily to check that in both groups of participants the trauma-films had a comparable effect of inducing a negative mood (i.e. were distressing) and were arousing, hence being analogous to the experience of witnessing real-life trauma.

2.3.5 *Intrusive memories - Intrusive memory diary (unpublished)*

Participants were required to fill out an online intrusive memory diary each evening for the 7 days of the study. The diary provided space to record up to 10 intrusive memories each day and required them to enter the time and date of the intrusion; a brief typed description of the content of the memory (such as where they were when it happened and what images were involved); and a rating of the level of distress associated with the intrusive memory ranging from 1 (Not distressing at all) to 10 (Highly distressing). This method is used in many other published studies utilising the trauma-film paradigm (Holmes & Bourne, 2008).

2.4 *Encoding materials*

Participants viewed three films with traumatic content involving humans and animals in distress. Film 1 depicted the aftermath of a motorway car accident, with footage of rescue workers cutting through a wreckage to retrieve a dead passenger, and another section involving rescue workers carrying a dead body. Film 2 involved footage of a traditional Spanish bullfight, in which a bull is initially tormented by the crowd in a stadium and then later escapes to the streets where it ends up injuring a man and then violently killing a young woman. Film 3 involved an almost continuous scene of a woman receiving an emergency intubation by ambulance workers following a car accident. These films were selected because their use in previously published research has reliably demonstrated that they induce intrusive memories (Pile, Barnhofer & WIld, 2015; Steil, 1997). The films were always displayed in the same order and were preceded by the following onscreen instructions: "*Whilst watching this film, focus on: How the people might have felt? What if this were to happen to you? Or someone in your family?"* Following these instructions, participants heard a brief verbal narrative read in a female voice that provided context for the film they were about to see, as suggested in a previous study (Krans, Naring, & Becker, 2009). For example, for the car accident film, participants were told that a car containing four passengers was involved and a description of their deaths or injuries was provided. The films were all of similar length and in total lasted for approximately 10 mins. The purpose of providing the onscreen written instructions and the extra verbal details was to give context to the films.

2.5 *Sleep assessment*

Actigraphy and sleep diaries were used to monitor sleep. Actigraphy was obtained using GENEActiv recorders (Activ Insights, Ltd., Kimbolton, UK), which contain a triaxial MEMS-accelerometer with a dynamic range of ± 8 g and a sensitivity of ≥ 0.004 g. Actigraphy has been shown to provide a reliable and valid way of assessing sleep–wake patterns that are comparable to laboratory based recording (Ancoli-Israel et al., 2003; Sadeh & Acebo, 2002). Participants in the current study were given GENEActiv devices and instructed to wear these on their non-dominant wrist at all times, with a sampling frequency set at 100Hz for the 7 day period. Raw data was extracted with GENEActiv PC software (v.2) and converted to 1-min epochs, then translated to sleep measures using a validated scoring template. True sleep time was used to measure compliance with the sleep manipulation, referring to the number of minutes slept excluding all periods of wakefulness. Daily sleep diaries were assessed to corroborate actigraphic data.

2.6 *Memory tasks*

At the end of the protocol one week after having watched the films, participants completed a visual recognition memory task and a verbal generative recognition task. The visual recognition task was comprised of 13 previously seen (old) and 13 foil (new) still images drawn from the three experimental films and three other similar unseen films also displaying traumatic content. Images were normalised for brightness and contrast. In order to increase difficulty, images were selected such that they did not depict the key central traumatic event during the film. At test, participants were instructed to answer Yes or No based on whether they thought they had previously seen the image on screen.

The verbal generative recognition task was comprised of 12 yes/no forced choice questions that referred to content of the traumatic films; four questions were devised for each film and they required participants to recollect specific episodic detail from the films to answer correctly. For example, "Did the bull attack a child in the street?" We term this task 'generative recognition' to reflect the fact that participants are provided with initial details of a film (e.g. that there was a bull, or child) which they should recognise, and then use this information to generate a search in memory for the correct answer. Thus, unless participants are guessing the answer, the task requires a more recall-like process.

2.7 *Procedure*

Figure 1 illustrates the design of the experiment. Participants were randomly allocated to the REM sleep deprived (REM-D; *N* = 26) or sleep control group (SC; *N* = 26) prior to arrival to the laboratory using a Microsoft Excel random number simulation. Group allocation was not revealed until after they had watched the trauma films. The initial test session lasted approximately 45 minutes and always occurred between 5.30-6.30pm. Upon arrival, participants provided written informed consent and then completed the IES-R, BDI-II, STAI, ISI, SSS and emotional reactivity measures. Additionally, female participants were asked to provide details of the stage of their menstrual cycle (days since last menstruation and average length of cycle).

Participants were told they would find out their group allocation after watching the trauma films. They were then left alone in the quiet testing room to watch the films and once these had ended, the experimenter returned and administered a second version of the mood and arousal reactivity questionnaires that had been completed earlier. Participants were then informed which experimental group they were in; however, before directions regarding sleep

were provided participants were given instructions on how to fill out an intrusive memory diary over the course of the week. An intrusive memory was described as a spontaneous, unintentionally recalled image or scene relating to the films that popped into their head. A standardised example of an intrusive memory was provided and contrasted to what a non-intrusive conscious memory would be. Additionally, participants were told to avoid discussing the content of the study with anyone over the course of the week in order to reduce the likelihood of overt rehearsal boosting later memory performance. Participants were sent an automated text message reminder every night of the study politely reminding them to complete their diary. Following instructions relating to the diary, participants were given directions regarding sleep:

REM-D group. Each participant's sleep diary from the previous week was used to plan individually tailored sleep deprivation that restricted their habitual night's sleep by half the number of hours they would usually sleep. For example, if a participant normally went to sleep at 11pm and woke at 7am, they were instructed to wake at 3am and remain awake for the whole of the next day. The experimenter provided an Actigraph device and explained that this would measure their sleep-wake cycle over the course of the week; the experimenter also checked a wake-up alarm had been set and time was devoted to ensuring each person had a sufficient amount of activities to do to keep them occupied throughout this morning period. Participants were asked to treat it as if they were awake for the day, and encouraged to get up, shower and go about their normal daily business. Almost all participants reported that this early morning period was primarily used for completing outstanding university assignments.

After this one night of sleep deprivation, participants in the REM-D group were told they were allowed to return to their normal sleep pattern from day 2 onwards, but asked not to nap and refrain from any substances that would interfere with their normal sleep cycle for the following week.

Sleep Control (SC) group. Participants in the SC group were provided with an Actigraph device and told to sleep normally for the following week, also refraining from napping or any sleep-interfering substances.

One week later, participants were asked to return to the laboratory in order to return their Actigraph device and receive compensation for participation; follow-up sessions always occurred at approximately 5pm and participants were given surprise recognition memory tests, described above. These were administered in counterbalanced order. The visual recognition task instructed participants that they were about to be tested on the films they saw in the first session; they were told they would be presented with a number of still images,

some of which were from these films, some of which were from other unseen films. Their task was to respond 'Yes' if they had seen the image and 'No' if not. Items were presented in a randomised order for 3s duration, with a black fixation cross presented on a grey screen for an ISI of 2s prior to each image. The next trial was initiated following participant keyboard response, and if no response was detected the trial was recorded as a miss.

During the verbal generative recognition task, participants were instructed that they were about to be presented with a number of statements related to the films they previously watched. They were told that their task was to determine whether each statement was true or false based on their memory for the particular film it related to. This was to be indicated by responding Yes or No if they agreed with the statement. Participants were provided with a verbal label in parentheses to indicate which of the three films the statement related to. For example, questions relating to Film 2 were followed by "(bull fight)". Each statement was presented in black Arial font on a grey background for a maximum duration of 10s with the same 2s ISI as in the visual task. The next trial was initiated following participant response, and no response was recorded as a miss.

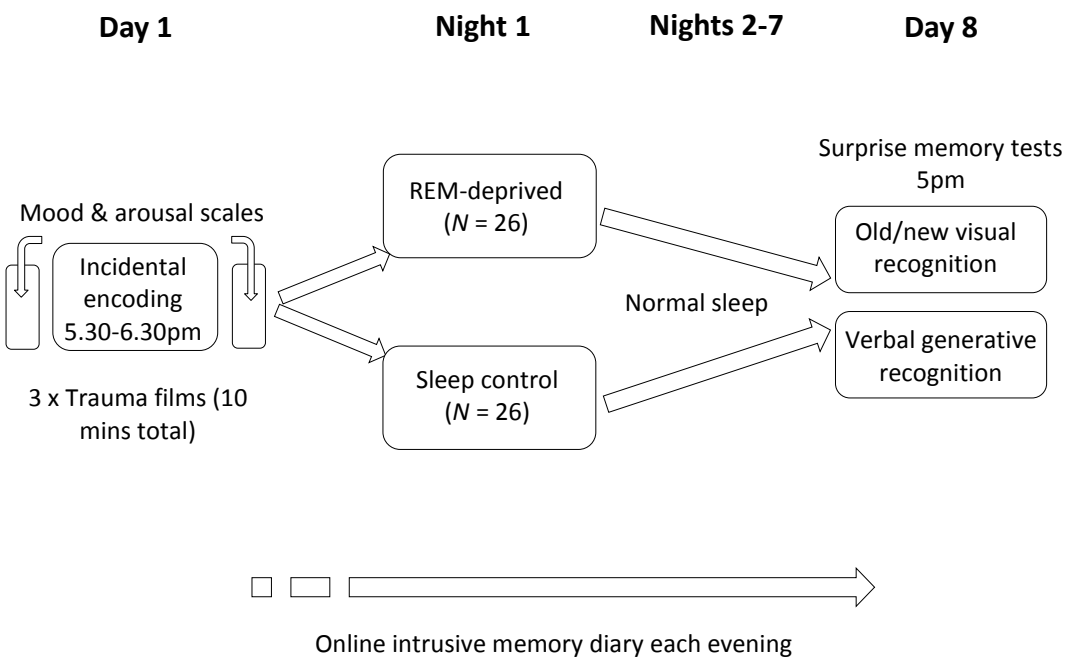

Figure 1. Experimental design overview. Participants completed mood and arousal visual analogue scales before watching three aversive films depicting real life incidents involving humans and animals in distress. After watching the films, mood and arousal measures were repeated and participants were randomly assigned to a REM deprived or sleep control group. REM deprived participants went to bed at normal time and woke after half their habitual night's sleep and stayed awake the rest of the following day. Sleep controls slept normally. On subsequent nights both groups slept normally at home. Over the experimental week an online intrusive memory diary was completed to record frequency and distress associated with intrusions. One week later, participants returned and completed two recognition memory tests.

All stimuli including films and memory tasks were viewed on a 15.5" screen laptop device at a comfortable viewing distance approximately 40cm from the participant. Trauma films were presented using VLC media player software and earphones were worn during video playback. Both memory tasks were administered using PsychoPy software (Peirce, 2007) with v and m keys labelled as 'Y' and 'N' for yes and no, respectively.

2.8 *Statistical Analyses*

All statistical analyses were conducted with α set at .05 unless otherwise stated. The data were assessed for normality and variables that violated parametric assumptions were square-root transformed, although raw untransformed values are reported to aid readability. [2] Moreover, homogeneity of variance was assessed via Levene's test and adjusted values are reported accordingly.

Demographic and sleep data were analysed using independent samples t-tests for between-group comparisons. Gender distribution was assessed via Chi-squared analysis.

For the analysis of intrusive memory data we were interested in the total number reported over the course of the week, but expected our main findings to emerge from days 1 and 2 due to the critical intervening period of sleep, or sleep deprivation in this period. For level of distress associated with intrusions we focused on the mean level assigned to intrusions on days 1 and 2, for the same reason.

For the visual recognition memory task, our primary measures were hits minus false positives (FPs), as well as signal detection measures of discriminability (*d'*) and response bias (*C*), calculated according to Macmillan & Creelman (1990). These measures take into account response bias in their calculation. Greater *d'* scores indicate a better ability to discriminate old from new items; *C* ranges from -1 to 1, with negative values indicating a liberal response bias (i.e. tendency to say 'yes' to items) and positive values indicating a more conservative response bias (tendency to say 'no').

All of the main analyses described above were computed using independent samples t-tests comparing the REM-D and SC groups. Estimates of effect size (Cohen's *d*) are also reported. Further, Pearson's correlations were used to investigate the relationship between mood, arousal and our critical memory measures (provided in Appendix III: Supplemental Analyses).

[2] Due to violations of normality in the data, the following measures were square root transformed for the purposes of carrying out parametric tests: day 1 and 2 intrusions; total intrusion days 2-7; total number of intrusions.

3. *Results*

Forty-eight (*N*=48) participants were included in the final intrusive memory analyses (*N* = 23 REM-D; *N* = 25 SC). Four participants were excluded due to not complying with sleep instructions over the first 24 hours of the protocol. Forty-seven (*N*=47) participants were included in the memory task analyses (*N* = 22 REM-D; *N* = 25 SC) as one participant in the SC group did not complete memory testing at the end of the protocol but their intrusion data were still used. Demographic data below is thus based on 48 participants.

3.1 *Demographics*

Independent samples t-tests confirmed there were no differences between the REM-D and SC groups in age, and no difference was found in scores on the IES-R, BDI-II, or STAI trait and state scales (*ps* > .32). Chi-squared analysis displayed no difference in gender distribution between groups: χ^2 (1, *N* = 48) = 0.67, *p* = .41. Table 1 shows demographic descriptives for the two groups.

Table 1. Demographic descriptive data.

	Group	
Measure *Mean* (*SD*)	REM-D (*N*=23)	SC (*N*=25)
Age	21.85 (4.51)	22.46 (3.36)
Gender	Male: *N* = 8 ; Female *N* = 18	Male: *N* = 7 ; Female *N* = 19
IES-R	0.65 (1.71)	1.96 (4.20)
BDI-II	2.65 (2.62)	1.96 (2.07)
STAI-trait	27.54 (6.52)	28.23 (7.85)
STAI-State	32.35 (9.05)	33.23 (9.22)

Note: REM-D = REM deprived, SC = sleep control, IES-R = Impact of Events Scale-Revised (Weiss & Marmar, 1996), BDI-II = Beck Depression Inventory-2nd Edition (A. T. Beck et al., 1996), STAI = State-Trait Anxiety Inventory (Spielberger et al., 1983).

3.2 *Sleep measures*

Table 2 displays sleep-related data for both groups. At baseline, the REM-D and SC groups did not differ in self-reported levels of dissatisfaction with their sleep pattern as measured by the ISI: *t*(46) = 0.67, *p* = .50; and they did not differ in terms of vigilance levels at time of testing

before watching the trauma films as measured by the SSS: $t(46) = 0.39$, $p = .70$. An independent samples t-test displayed a significant difference in actigraphic true sleep time between the groups on night 1 of the experiment: $t(46) = 12.06$, $p < .001$, $d = 3.49$. We further confirmed that participants in the REM-D group complied with instructions by calculating night 1 sleep mins as a proportion of their average night's sleep over the rest of the study (*Mean* = .50, *SD* = .08). As expected following mild sleep deprivation, there was a tendency for the REM-D group to have more sleep (recovery sleep) on the second night: $t(46) = 1.67$, $p = .10$, $d = 0.48$, and the SC group to have more overall: $t(46) = 1.53$, $p = .13$, $d = 0.44$, but neither result was significant. Crucially, the data confirm that the REM-D group were indeed successfully deprived of sleep in the latter half of the night on the first day of the study.

Table 2. Sleep data recorded over study period.

	Group	
Sleep Measure *Mean* (*SD*)	REM-D (*N*=23)	SC (*N*=25)
ISI	3.11 (2.42)	3.54 (2.37)
SSS	2.15 (0.67)	2.23 (0.51)
Night 1 mins	214.43 (54.78)	419.68 (62.43)
Night 2 mins	481.96 (89.43)	437.00 (96.58)
Total sleep mins	2752.52 (392.51)	2915.82 (348.02)

Note: REM-D = REM deprived, SC = sleep control, ISI = Insomnia Severity Index (Morin, 1993), SSS = Stanford Sleepiness Scale (Hoddes et al., 1973). Sleep time calculated as true sleep time (total sleep mins minus wake mins) via actigraphy.

3.3 *Mood and arousal reactivity*

Differences in pre-post mood and arousal measures were computed as measures of reactivity to the films. To control for baseline differences in mood and arousal, the difference in scores was calculated as a proportional rather than absolute difference. Thus, the reactivity measures reflect the percentage change – positive or negative – in scores. There was a mean reduction of 37% (*SD* = 17) in mood following the films; arousal had a mean increase of 10% (*SD* = 27). Independent t-tests showed the two groups did not differ in these reactivity measures (*p*s > .33). Thus, the trauma films were successful in inducing a notable shift toward a more negative mood, with a concomitant increase in arousal.

3.4 *Intrusive memories*

Our analyses focus on the number of intrusive memories recorded over the study protocol and the distress levels associated with them. For level of distress, we computed mean scores for each day for each participant. For example, if a participant had two intrusive memories on a day and recorded one as being 5/10 distress and the other 3/10, the mean given for that day would be 4.

3.4.1 *Frequency*

A total of 144 intrusive memories were recorded with 88% of the sample recording at least one. Figure 2 displays the frequency of intrusions over the week for both groups. The mean number of intrusive memories on day 1 did not differ between the REM-D and the SC group $t(46) = 1.03$, $p = .31$, $d = 0.30$.

For number of intrusions on day 2, there was no difference between the REM-D group and the SC group: $t(46) = 0.004$, $p = .99$, $d = 0.00$. Further, we found no significant difference in number of intrusive memories recorded over days 2-7 between the REM-D group and the SC group: $t(46) = 0.83$, $p = .41$, $d = 0.22$[3].

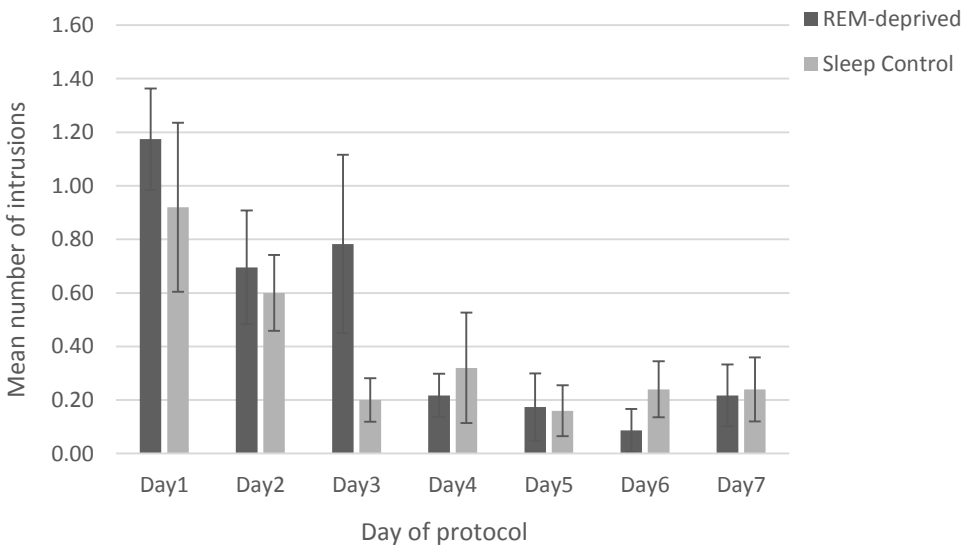

Figure 2. Mean intrusion frequency on each day of the protocol (error bars represent SEM).

[3] Whilst the difference in intrusive memory frequency on Day 3 visually appears significant, a post-hoc analysis revealed no statistical difference due to the large variability in data.

3.4.2 *Distress*

The mean level of distress associated with all intrusive memories was 3.30 (*SD* = 1.70) for the whole sample, suggesting that intrusive memories did not evoke a high degree of negative emotion. Figure 3 displays mean level of distress associated with intrusions over days 1 and 2 and the rest of the protocol for each group. As expected, for intrusions on day 1 mean distress levels did not differ between the REM-D group (*N* = 16) and the SC group (*N* = 15): *t*(29) = 1.16, *p* = .26, *d* = 0.40. For intrusions on day 2 following the sleep manipulation, a marginal trend was found in mean distress levels between the REM-D group (*N* = 11) and the SC group (*N* = 13): *t*(14) = 2.00, *p* = .07, *d* = 0.84, such that REM deprived participants experienced more distress associated with intrusions.

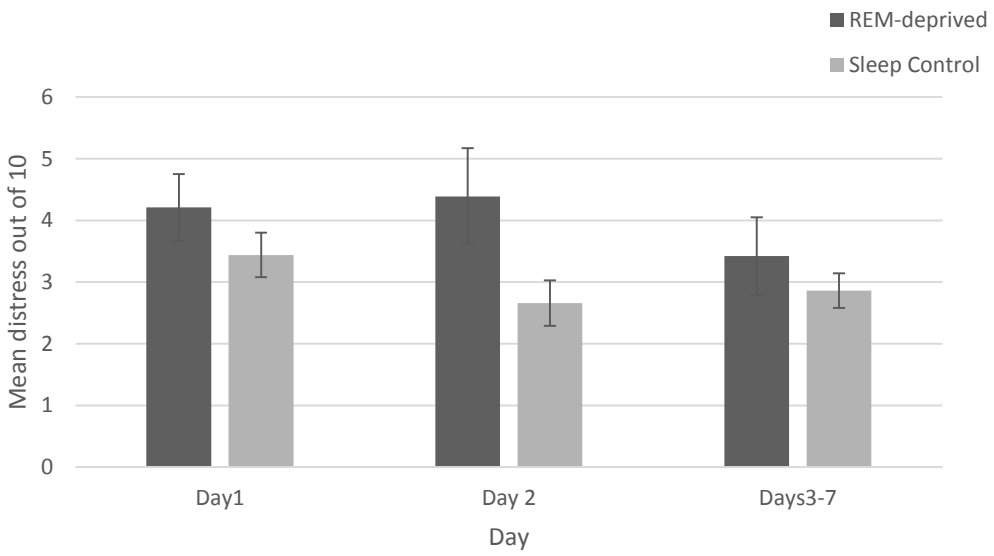

Figure 3. Mean distress associated with intrusions by day of protocol (error bars represent SEM).

3.5 *Memory performance*

Table 3 displays performance on both memory tasks. On the visual recognition memory task, no difference was found between REM-D and SC groups on hits minus FPs, *t*(45) = 0.02, *p* = .98, *d* = 0.06; *d'* sensitivity, *t*(45) = 0.15, *p* = .88, *d* = 0.04; or *C* bias, *t*(45) = 0.36, *p* = .72, *d* = 0.09. This suggests both groups were equally good at discriminating old from new items, and were both comparably conservative in their responding: they had a tendency to reject items rather than accept them.

For the generative recognition task, a significant difference was found between groups in proportion of correct answers, $t(45) = 2.03$, $p = .05$, $d = 0.62$, with the REM-D group performing worse than the SC group.

Table 3. Memory performance on visual recognition and verbal generative recognition tasks.

	Visual old/new recognition task			*Verbal generative recognition task*
	Hits-FPs	*d'*	*C*	Proportion
REM-D (*n* =22)				
Mean (SD)	.50 (.18)	1.59 (0.97)	.17 (.49)	.63 (.14)
SC (*n* = 25)				
Mean (SD)	.49 (.17)	1.55 (1.00)	.21 (.35)	.72 (.15)*

Note: REM-D = Rapid eye movement sleep deprived group; SC = sleep control group; FPs = false positives, *d'* = signal detection measure of discriminability where higher scores indicate better ability to discriminate old from new items; *C* = signal detection measure of response bias indicating tendency to respond old to items where positive values indicate conservative bias and negative values indicate liberal bias; * = $p < .05$.

4. *Discussion*

The present study set out with the aim of investigating the effect of REM sleep deprivation on involuntary and voluntary memory using the trauma-film paradigm. After exposing participants to aversive films, participants slept normally or were deprived of REM sleep for one night. We measured the occurrence and distress associated with intrusive memories and gave two types of explicit memory test after a one-week delay. Contrary to predictions, our findings showed that REM deprivation using a split-half night paradigm did not have an effect on the occurrence of intrusive memories compared to normally rested participants; we provide some evidence however that sleep deprivation led to enhanced emotional reactivity to these intrusions. For explicit memory after a one week delay, we found that performance on a visual recognition task was equivalent between our groups, but performance was impaired on our generative recognition task, in which successful performance requires additional recall-like processes.

4.1 *Consolidation of involuntary memories*

Unwanted intrusive memories form a core part of the clinical diagnosis in PTSD and are highly distressing to patients diagnosed with the disorder. Recent clinical experimental work has

begun to examine the mechanisms by which aversive events are encoded as flashbacks, with the aim of developing interventions that can be applied in the immediate aftermath of trauma to specifically target such processes (Holmes et al., 2009; Krans, Näring, Holmes, & Becker, 2009). Whereas previous studies have investigated the utility of using an active cognitive intervention during or following exposure to trauma to reduce intrusions, the present study examined for the first time a straightforward behavioural manipulation of sleep. The fact that intrusive memory development was not affected by REM deprivation in the current study runs contrary to the proposal that sleep deprivation after trauma could prevent the development of PTSD symptoms (e.g. Holland & Lewis, 2007; Kuriyama, Soshi, & Kim, 2010).

Our prediction that number of intrusions would be lower in the REM-D group was based on the fact that several studies have found REM sleep is related to enhanced explicit memory for emotional information (Groch et al., 2013; Nishida et al., 2009; Payne, Chambers, & Kensinger, 2012; Wagner et al., 2001, 2006), and recent empirical work highlights the similarities between involuntary and voluntary forms of memory for emotional stimuli (Staugaard & Berntsen, 2014). Moreover, at a functional level, intrusive memories for analogue trauma have displayed a characteristic neural signature at encoding that, among other networks, implicates emotional pathways and some overlap with those involved in explicit memory (Bourne et al., 2013; Clark et al., 2014). Therefore, we speculated that the consolidation of involuntary memories would also be impaired following REM deprivation.

Instead, our findings are more compatible with clinical theories that emphasise the differences between intrusive and voluntary memories, such as dual-representation theory (DRT; Brewin et al., 1996, 2010; Brewin, 2001). According to DRT, flashbacks are highly sensory in nature and are a form of enduring perceptual-based memory that is not contextualised in the same way as a normal episodic memory (Brewin, 2014). The theory therefore predicts less of an involvement of the hippocampus and medial temporal lobe during the formation of sensory-based memories; in support, a recent fMRI study by Whalley et al. (2013) tested the hypothesis that flashbacks primarily involve the activation of a more dorsal-visual stream including the motor cortex, insula and amygdala, as compared to the ventral-visual stream which would involve inferior and middle temporal regions involved in normal episodic memory. They largely confirmed this hypothesis since PTSD patients' flashbacks activated the more ventral-visual route.

If memories that become intrusive are formed and retrieved largely independent of the normal episodic memory system, this would explain why REM sleep does not help to consolidate them. A recent model outlining the specific functions of REM sleep in both

emotional processing and memory consolidation particularly focuses on the role of the hippocampus in these processes (Goldstein & Walker, 2014). The authors suggest that during REM sleep there is a reduction in adrenergic activity and increase in cholinergic activity so the hippocampus can engage in a dialogue with outer cortical modules without being negated by high amygdala activity, as is the case during encoding at times of high stress. Whereas this amygdalo-hippocampal-cortical consolidation process may be key for the consolidation of explicit voluntary memories during REM sleep, involuntary memories encoded via perceptual processing may undergo a qualitatively different course of consolidation, operating over different stages of sleep.

Whilst this is a plausible explanation for our findings, several methodological considerations must be taken into account in interpreting our intrusion data. For example, the overall number of intrusive memories was lower than some studies employing the trauma-film paradigm, but is comparable to other published studies in which between-group effects were reported (e.g. Holmes et al., 2004). A further reason for the lack of difference between the groups could be due to consolidation processes operating in both the immediate waking and sleeping hours following exposure to the films. Additionally, it may be that consolidation processes occurring in the first half of the night were sufficient to result in comparable involuntary retrieval. Although the split-half night paradigm has the advantage of allowing participants to sleep in their normal environment, it is not 100% effective at blocking REM sleep, meaning the REM achieved in the REM-D group may have been sufficient for comparable consolidation as the SC group.

In our analysis of the distress associated with intrusions, we found participants in the REM-D group had an attenuation in responses in the day following sleep deprivation, compared to a tendency for a reduction of distress in the sleep control group. We expected this finding due to the fact that REM sleep is crucial not only for post-event emotional consolidation but also serves the function of 'emotional recalibration', preparing us each day for appropriate emotional reactivity to events (Goldstein & Walker, 2014; Gujar, McDonald, Nishida, & Walker, 2011). The spontaneous and involuntary nature of flashbacks, as well as their tendency to involve visual representations of the most emotionally charged parts of events is often what fuels the distress associated with them. Moreover, sudden activation in the absence of top-down executive control means that they transgress the normal emotion-regulation processes available during voluntary recall. Accordingly, REM deprivation may increase emotional reactivity to stimuli (e.g. Rosales-Lagarde et al., 2012). Although ratings did not increase in the current study, the attenuation of distress levels associated with intrusions following sleep

deprivation in the REM-D group suggests that this naturally therapeutic process has failed to occur.

4.2 *Consolidation of explicit memory*

Thus far, discussion in the literature regarding the potential role of sleep deprivation in reducing PTSD symptoms has been derived primarily from experimental studies assessing the effect of sleep on emotional recognition memory for single items, often from the IAPS dataset (Lang et al., 2005). Overall, the behavioural evidence from these studies is rather mixed, which we have interpreted as providing limited evidence for the notion of therapeutic sleep deprivation (Illman & Wild, *this volume*). The present data extend this literature by examining recognition memory performance for analogue trauma. Findings from our visual recognition memory task suggest that REM sleep deprivation did not lead to differences in standard measures of recognition memory performance one week after exposure. We opted to test voluntary memory after a one-week delay because testing memory earlier in the protocol may have affected the development of intrusions (see Krans, Näring, et al., 2009), which were our main interest in this study. It could be that this extended delay provided too long a period to be able to distinguish between the REM-D and SC groups due to interference and forgetting. However, by incorporating a second memory task that relies on an alternative route to retrieval, we display that such an effect is not uniform across all types of memory. Performance was significantly impaired on a generative recognition task, in which a more effortful, strategic search in episodic memory was required to accept or reject items. The longer retrieval time provided in this task (10s) also encouraged this, compared to the relatively speeded 3s given in the visual recognition task.

An impairment on the generative recognition task suggests that REM deprivation interfered with consolidation of the network responsible for emotional episodic memory retrieval, which relies on prefrontal and parietal cortices, hippocampi and amygdalae (see Buchanan, 2007, for a review). This finding builds on previous studies in which various forms of emotional recognition memory performance were found to be associated with characteristics of REM sleep specifically (Groch et al., 2013; Payne et al., 2012; Wagner et al., 2001, 2006). Notably, other studies failed to find a boost in emotional memory during REM, or sleep in general (Baran et al., 2012; Morgenthaler et al., 2014), meaning there is still some controversy over the importance of REM in the literature. The fact that we detected an impairment after one week suggests that the trauma-film paradigm is a useful way of measuring emotional memory, with frontally mediated recall processes potentially being more sensitive to the effects of REM deprivation than those in single item recognition memory. Extending the use of this paradigm

and incorporating free recall measures will no doubt help to clarify some of the inconsistencies in the literature.

4.3 *Limitations and future research*

Research evaluating early intervention strategies in PTSD has been gathering pace in recent years, with other studies also looking at targeting peri-traumatic processes, or processes occurring just after exposure to analogue trauma (see Brewin, 2014, for a review). Although the trauma-film paradigm has been well studied and widely accepted as a reasonable experimental analogue, it is not without its limitations. For example, whilst watching films depicting scenes that meet the DSM diagnostic criteria for trauma seems an improvement over viewing static images, real-life trauma involves the elicitation of emotional responses far greater than those experienced whilst watching an aversive film. Moreover, intrusive memories are often the primary dependent measure of interest, but some evidence suggests that the very way in which instructions are provided to aid their collection influences their characteristics (Vannucci, Batool, Pelagatti, & Mazzoni, 2014), calling into question how far we can generalise data to the real world. An inherent problem with this research area is working within the boundaries of ethical constraints: how real-life can we actually make this research? Ultimately, it will only be well-designed studies with trauma-exposed people that will provide more definitive answers to some of the theoretical and clinical questions posed by researchers.

We have provided an explanation of our intrusion findings based on memory consolidation processes, but another factor at play is the role of post-event cognitive processes and coping strategies. For example, it is known that post-event rumination and thought suppression are related to intrusive memory development (Laposa & Rector, 2012; Regambal & Alden, 2009), which we did not measure in our sample.

With regards to the sleep manipulation, the split-half night paradigm was useful as an initial exploration of the effects of depriving REM sleep on intrusive memories, but future studies would benefit from using polysomnography. The sleep and emotional memory consolidation field has already produced a number of high quality studies incorporating quantitative sleep measures and even fMRI data; the recent interest in mapping out the neural signature of flashbacks during encoding and retrieval could be complemented by further imaging work examining the effect of sleep consolidation processes on such neural pathways.

Participants all completed encoding at the same time to avoid circadian confounds. However, another limitation is that most participants went to sleep at the end of the proposed critical window of 6 hours that is important for post-learning memory consolidation (Walker et al., 2003), meaning we cannot exclude the possibility that the critical portion of consolidation of involuntary memories from the films had already been completed in this time. However, the importance of this wakeful post-learning period for consolidating involuntary memories is yet to be investigated, meaning that future research comparing the time-course of voluntary and involuntary consolidation through both wake and sleep will be necessary to unravel this issue.

4.4 *Conclusions*

The present study has demonstrated, through a simple behavioural manipulation, that REM sleep deprivation does not reduce the number intrusive memories experienced in response to analogue trauma. Moreover, consolidation of episodic memory appeared to be impaired one-week later but only when probed via recall-like processes. A major question is how our findings directly apply to the foregoing discussion in this field of whether sleep deprivation following trauma would have any therapeutic value. Put simply, our data do not support this contention. This is because although one form of voluntary memory retrieval was impaired, crucially, the occurrence of intrusive memories was not reduced and the distress associated with them did not reduce either.

Whilst this study has provided a glimpse into how effective a sleep manipulation would be, the issue of sleep is far more complex in the real-world. Sleep problems may be a risk factor for PTSD in the first place, and sleep abnormalities following trauma then create a vicious cycle in this disorder, maintaining the symptoms (Kobayashi, Boarts, & Delahanty, 2007; van Liempt, 2012). Because sleep naturally becomes disrupted following times of high stress, it is likely that pharmacological interventions will have more success. Studies now show that we can block consolidation of some memory traces following learning (see Lonergan, Olivera-Figueroa, Pitman, & Brunet, 2013), but manipulate and enhance others during sleep (Diekelmann, 2014). It is unclear if researchers will ever find the Holy Grail method of blocking consolidation of pathogenic involuntary and voluntary trauma memories. In this pursuit of early-intervention techniques, however, we must be careful not to overlook the important ethical issues related to wiping out our memory traces.

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6. *Appendices*

6.1 *Appendix I - Letter of ethical approval*

Nathan Illman
Department of Psychology
Institute of Psychiatry
Addition Sciences Building
4 Winsor Walk
SE5 8AF

14 March 2014

Dear Nathan Illman

PNM/13/14-57 Examining the link between sleep and intrusions after exposure analogue trauma.

Review Outcome: Full Approval

Thank you for sending in the amendments/clarifications requested to the above project. I am pleased to inform you that these meet the requirements of the PNM and therefore that full approval is now granted.

Please ensure that you follow all relevant guidance as laid out in the King's College London Guidelines on Good Practice in Academic Research (http://www.kcl.ac.uk/college/policyzone/index.php?id=247).

For your information ethical approval is granted until 14/03/2017. If you need approval beyond this point you will need to apply for an extension to approval at least two weeks prior to this explaining why the extension is needed, (please note however that a full re-application will not be necessary unless the protocol has changed). You should also note that if your approval is for one year, you will not be sent a reminder when it is due to lapse.

Ethical approval is required to cover the duration of the research study, up to the conclusion of the research. The conclusion of the research is defined as the final date or event detailed in the study description section of your approved application form (usually the end of data collection when all work with human participants will have been completed), not the completion of data analysis or publication of the results. For projects that only involve the further analysis of pre-existing data, approval must cover any period during which the researcher will be accessing or evaluating individual sensitive and/or un-anonymised records. Note that after the point at which ethical approval for your study is no longer required due to the study being complete (as per the above definitions), you will still need to ensure all research data/records management and storage procedures agreed to as part of your application are adhered to and carried out accordingly.

If you do not start the project within three months of this letter please contact the Research Ethics Office.

Should you wish to make a modification to the project or request an extension to approval you will need approval for this and should follow the guidance relating to modifying approved applications: http://www.kcl.ac.uk/innovation/research/support/ethics/applications/modifications.aspx
The circumstances where modification requests are required include the addition/removal of participant groups, additions/removal/changes to research methods, asking for additional data from participants, extensions to the ethical approval period. Any proposed modifications should only be carried out once full approval for the modification request has been granted.

Any unforeseen ethical problems arising during the course of the project should be reported to the approving committee/panel. In the event of an untoward event or an adverse reaction a full report must be made to the Chair of the approving committee/review panel within one week of the incident.

Please would you also note that we may, for the purposes of audit, contact you from time to time to ascertain the status of your research.

If you have any query about any aspect of this ethical approval, please contact your panel/committee administrator in the first instance (http://www.kcl.ac.uk/innovation/research/support/ethics/contact.aspx).
We wish you every success with this work.

With best wishes

Yours sincerely

6.2 *Appendix II - Unpublished measures*

6.2.1 *Trauma Screener*

Many people have lived through or witnessed a very stressful and traumatic event at some point in their lives. Indicate whether or not you have experienced each traumatic event listed below by marking **Y** for Yes or **N** for No.

Serious traffic accident, (e.g., car, bike, train, or boating accident) **(Y/N)**

Serious other accident, fire, or explosion (for example, accident at work, fire at home) **(Y/N)**

Natural disaster (for example, tornado, hurricane, flood, or major earthquake) **(Y/N)**

Non-sexual assault (for example, being mugged, physically attacked, shot, stabbed, or held at gunpoint) **(Y/N)**

Seriously injuring or killing someone else **(Y/N)**

Sexual assault **(**for example, rape or attempted rape) **(Y/N)**

Military combat or a war zone **(Y/N)**

Please indicate whether you were: civilian _____ / military personnel _____

Terrorist attack (e.g., bombing**) (Y/N)**

Unwanted sexual contact when you were younger than 18 with someone who was 5 or more years older than you (for example, contact with genitals, breasts) **(Y/N)**

Imprisonment (for example, prisoner of war, hostage) **(Y/N)**

Torture **(Y/N)**

Life-threatening illness **(Y/N)**

Witnessing others die / being seriously hurt **(Y/N)**

Sudden, traumatic death of significant other **(Y/N)**

Life-threatening illness of significant other **(Y/N)**

Other traumatic event

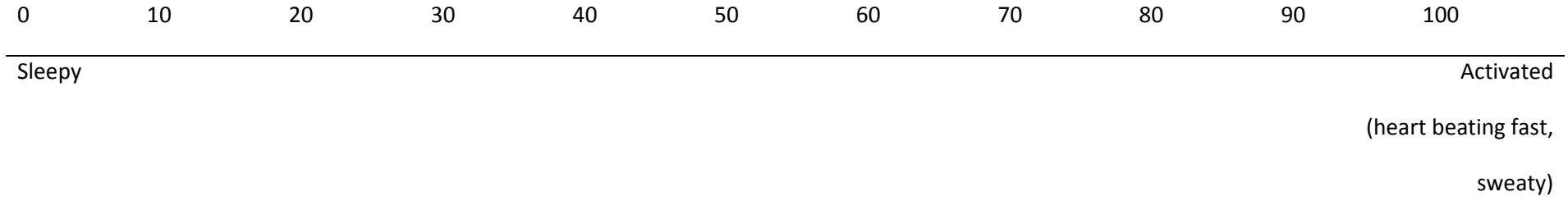
Please specify:……

If YES to any of the above, please also place a tick (✓) next to the item if you experienced distressing unwanted memories of the event (flashbacks, nightmares, unwanted thoughts?)

6.2.2 *Emotional reactivity scales*

Please rate your current mood:

How activated do you currently feel



6.2.3 *Intrusive Memory Diary*

*Required

Participant number:*

What are intrusive memories?

Intrusive memories are spontaneously (not deliberately recalled) image-based memories or scenes that may pop into your mind.

INSTRUCTIONS

Over the next seven days, we would like you to record in this diary all of the intrusive memories you experience for the films you watched in the laboratory. To help you remember to complete the diary each day, we will be sending you an automated text message reminder each evening.

Before you go to bed each night, simply record how many intrusive memories you had that day by filling in a separate box for each on the form below. There are three components to each intrusive memory you record:

1) The date and time you had the intrusive memory (just select from the drop-down boxes).

2) Some brief details of the intrusive memory (for example, what you were doing when you had it, or where you were - you are given space to write a few details for each memory).

3) Finally, record how distressed you were when you experienced the intrusive memory (click on the relevant button ranging from 1 'Not distressing at all' to 10 'Highly distressing').

There are more boxes available than you will probably need but this is simply to accommodate for the possibility that some people will experience more intrusive memories than others. It does not matter how many intrusive memories you have, just try your best to record them as accurately as possible if they do occur.

When you have finished filling in your intrusive memories for the day, check you have entered the correct participant number (this is crucial for us to link up your responses), and click 'Submit'. The following day, simply go back to the link you were emailed and fill out your responses as per above.

All data collected in this diary will be held anonymously and securely. No personal data is asked for or retained.

Intrusive memory 1

Intrusive memory 1: Date and time

Example: 03/05/2013 11:30 AM

Intrusive memory 1: Details

Provide brief details of the intrusive memory, such as when it occurred and what the content was.

Intrusive memory 1: Level of distress

Click a button to indicate level of distress.

	1	2	3	4	5	6	7	8	9	10	
Not distressing at all	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	Highly distressing

6.3 *Appendix III - Supplemental Analyses*

Relationship between reactivity, intrusions and memory strength

To explore the influence of emotional and arousal reactivity on intrusive memory development we computed Pearson's correlations between these measures. Mood reactivity significantly correlated with number of intrusive memories on day 1, before the sleep manipulation (r = -.29, p = .04) indicating that a greater shift toward negative mood was related to having more intrusive memories. Arousal reactivity showed no correlation with number of intrusions (r = -.06, p = .67). For the subsequent days of the study, we analysed the two groups separately and found no significant correlation between either mood or arousal activity and the total number of intrusive memories over days 2-7 of the protocol (ps > .13).

We next examined if memory performance on the visual and verbal generative recognition tasks was related to mood and arousal reactivity, as well as number of intrusive memories. In the whole sample, mood reactivity was unrelated to *d'* scores on the visual recognition task (r = .00, p = .99) but a significant correlation was found with arousal reactivity (r = .32, p =.025), suggesting a higher level of arousal resulting from viewing the films boosted later visual recognition memory performance. No significant correlations were observed between performance on the generative recognition task and mood and arousal reactivity (r = -.06 p =.70; r = -.04, p =.80, respectively). Moreover, total number of intrusive memories on day 1 did not correlate with memory performance in the visual recognition (r = .15 p =.29) or generative recognition tasks (r = .21, p =.15).

To examine the potential effect of sleep on this relationship we explored the impact of intrusion frequency on days 2-7 separately in the REM-D and SC groups. This revealed a significant association between number of intrusions and *d'* score in the SC group (r = .49, p = .01), but not in the REM-D group (r = -.01, p = .96). Number of intrusions on days 2-7 did not correlate with performance on the generative recognition task in either the REM-D (r = .33, p = .12), or SC group (r = .15, p = .46). This suggests that the occurrence of intrusive memories was related to better visual recognition memory performance but only in participants who were normally rested.

Effects of gender and menstrual cycle

We repeated all main analyses with independent t-tests comparing men and women in our key measures (mood and arousal reactivity; number of intrusions and associated distress; visual and verbal memory performance). There were no gender effects observed in any of the above analyses (*p*s > .18), except for emotional reactivity to the films, where a significant difference was found: $t(50) = 2.29$, $p = .03$. This was such that males displayed less reduction in mood (*Mean* = -28%, *SD* = 21) compared to females (*Mean* = -40%, *SD* = 14) after watching the films. In terms of correlations, the previously observed relationship between arousal reactivity and *d*' scores was found to be specifically in males ($r = .55$, $p = .04$), with no significant association found in females ($r = .29$, $p = .08$).

One-way ANOVAs were computed for the main dependent measures using women's position in their menstrual cycle as the group factor (Early *N* = 8; Mid *N* = 14; Late *N* = 14). None of the analyses returned significant main effects (*p*s >.33) except for emotional reactivity: $F(2, 35) = 3.63$, $p = .04$, which was a result of women in their mid-cycle having a more pronounced reduction in mood (*Mean* = -48%, *SD* = 14) compared to both early (*Mean* = -33%, *SD* = 14) and late-cycle (*Mean* = -37%, *SD* = 13) women.

SERVICE EVALUATION PROJECT

Community-based anger workshops provided by Southwark Psychological Therapy Service: Assessment of efficacy and attrition.

Supervised by Dr June Brown

Service Evaluation Project

CONTENTS

TABLES

Abstract

The effectiveness of psychological treatments for problem anger are becoming increasingly established, but this is still an area of mental health that has been under researched. Here, we present an evaluation of a series of one-day workshops targeting problem anger with a cognitive-behavioural approach. We aimed firstly to evaluate the effectiveness of this low intensity intervention, and second, to further examine reasons why attrition in anger treatments is frequently high. In terms of outcome, we found a significant reduction in anger provocation among 50 workshop participants at 1 month follow-up. Reductions in depression, anxiety and impact on social functioning were not statistically significant. Attrition was examined in two ways: first, quantitatively assessing differences in outcome measures between participants who attended the workshops with those who dropped-out following an initial introductory talk. We found no reliable difference between these two groups in baseline levels of anger, depression and anxiety. Second, a semi-structured telephone interview was designed with the aim of recruiting non-attenders to provide feedback on their specific reasons for dropping out. However, none of the non-attenders agreed to participate in the study. We conclude that this anger intervention was effective in this small study and suggest future studies assess participant motivation as a means to reduce attrition.

1. *Introduction*

1.1 *Psychological approaches to anger*

Anger is one of the most basic human emotions, comprising a complex blend of physiological, psychological and behavioural components. According to one recent definition provided by DiGiuseppe and Tafrate (2007), anger can be defined as "a subjectively experienced emotional state that is elicited by a perception of threat. It is associated with cognitions focused on others' misdeeds and is communicated by a variety of behaviours influenced by social roles, learning history, and environmental contingencies" (p.31). When anger is not regulated well and is expressed outward, there are potentially harmful consequences in the case where aggression is enacted; however, anger can also be 'bottled up' in an unhealthy way too, causing distress to an individual. Thus, there are individual differences in the extent to which we all regulate this emotion both internally and externally.

Defining anger has been problematic due to its similarity to other mental or emotional states and expressions. For most people, episodes of anger are experienced and dealt with in a healthy way. However, for some, anger is experienced frequently and intensely and its destructive effects can cause serious impairment in day-to-day life. These people can be described as experiencing *problem anger*, and increasing evidence suggests this is linked to a variety of social, physical and mental health problems. For example, chronic anger is linked to low levels of social support (DiGiuseppe & Tafrate, 2007); an increased susceptibility to minor illnesses such as common colds and flu, but also to more noxious conditions such as Coronary Heart Disease (Williams *et al*., 2000) and a reduced ability to use adaptive coping strategies (Novaco, 1978).

Despite mounting evidence for the negative effects of problem anger, it has received little attention in the mental health arena, as compared to depression and anxiety. The lack of attention is evidenced by the fact that anger is not recognised as a discrete clinical disorder in the DSM-V or ICD-10. Instead, it is generally considered a symptom or component of another condition, rather than an individual issue worthy of treatment in its own right (Lench, 2004). This lacuna in diagnostic classification unfortunately means there is a dearth of empirical research into this area, which in turn creates a wider concern: problem anger comes with a cost to the individual and to society as whole, and if effective clinical treatments are not widely available, then this continues. A recent report by the Mental Health Foundation emphasises this stark point, as their findings suggest that many primary care health professionals simply do not know what to do with clients presenting with complaints of problem anger (Mental Health Foundation, 2008).

1.2 *Who experiences problem anger?*

In the general UK population, a recent survey of 2000 people shed light on the prevalence of problem anger, and people's perceptions of it (Mental Health Foundation, 2008). Nearly one-third of people reported they have a friend or family member who has trouble controlling their anger, and 12% of people say they have trouble controlling their own anger. In terms of impact of anger, 20% of people reported ending a relationship because of the way someone behaved when angry. Differences also emerged between certain age groups; older people report far less concern with anger with respect to themselves, and peers, than younger people. In terms of gender, research examining differences between males and females in the experience and expression of anger is largely considered to be equivocal (DiGiuseppe & Tafrate, 2007; Sharkin, 1993).

Although there is a strong case to be made to study anger as a mental health condition itself, research suggests that it plays a significant role in a number of disorders. For example, 'anger attacks' occur in up to 30-40% of patients with major depression; these resemble the features of a panic attack but lack the fear and anxiety affects (Fava & Rosenbaum, 1999). Anger has also been examined in relation to anxiety disorders. As discussed by Moscovitch, McCabe, Antony, Rocca, and Swinson (2008), this avenue of research has emerged from the fact that anxiety is frequently conceptualised as the 'fight or flight' response, yet the literature has overwhelmingly focused on behavioural expression of the 'flight' component, such as avoidance, withdrawal and safety seeking behaviours (see Clark, 1999, for example). However, a number of studies have found evidence that various anxiety disorders are associated with manifestations of the 'fight' response, in the form of anger. For example, Erwin, Heimberg, Schneier and Liebowitz (2003) found Social Phobics (SP) to have significantly higher levels of anger on a number of subscales of the State-Trait Anger Expression Inventory (STAXI; Spielberger, 1988). Moreover, higher subjective levels of anger have been found in, or proposed to be involved in: Panic Disorder (PD) (Baker, Holloway, Thomas, Thomas, & Owens, 2004; Fava *et al*., 1993), Obsessive-Compulsive Disorder (OCD) (Radomsky, Ashbaugh, & Gelfand, 2007; Whiteside & Abramowitz, 2004, 2005) and Generalised Anxiety Disorder (GAD) (Mennin, Heimberg, Turk, & Fresco, 2006). Whereas anger may be characteristic of these anxiety disorders, a recent meta-analytic review by Olatunji, Ciesielski and Tolin (2010) indicated that post-traumatic stress disorder (PTSD) is associated with significantly greater anger difficulties than any of these. Interestingly, Moscovitch et al. (2008) found that most of the significant differences in anger measures between patients and controls were absent after

controlling for depression scores, which has been suggested to be a result of an increase in the higher-order construct of *negative affect* across all anxiety disorders (Brown, Chorpita, & Barlow, 1998). It is clear then, that one must consider the multidimensional nature of anger and how this emotion may interact with other psychological co-morbidity.

1.3 *Psychological treatments for anger and their efficacy*

A variety of treatments exist for dealing with anger problems, but as Beck and Fernandez (1998) state in their review, the majority of these are largely based on cognitive-behavioural therapy (CBT) principles, such as Novaco's (1975; 1993) adaptation of 'stress inoculation training' (SIT; Meichenbaum, 1977, 1985). Cognitive-behavioural approaches break anger down into its constituent parts: trigger → appraisal → anger → behavioural expression → outcome sequence, and different interventions aim to target one or more of these (Deffenbacher, 2011).

The multifaceted nature of anger problems is represented by the variety of different treatment populations studied. For example, there has been cognitive-behavioural treatment for specific, but non-clinical groups such as high-anger drivers (Deffenbacher, Filetti, Lynch, Dahlen, & Oetting, 2002) and police-officers (Gerzina & Drummond, 2000), as well as a variety of clinical populations such as people with intellectual disability (Nicoll, Beail, & Saxon, 2013) and brain injury (Medd & Tate, 2000). Unsurprisingly, there have also been a number of studies investigating anger management in the context of offender samples (Kassinove & Toohey, 2014).

The overall efficacy of these psychotherapeutic treatments for anger has been reviewed thoroughly in recent years in a number of meta-analyses (Beck & Fernandez, 1998; Bowman Edmondson & Cohen Conger, 1996; Del Vecchio & O'Leary, 2004; DiGiuseppe & Tafrate, 2003; Saini, 2009; Tafrate, 1995). These have all reported consistently that current treatments produce at least moderate effect sizes. Some of the more recent of these reviews have specifically assessed the effect of different types of interventions on a variety of anger outcome measures. This has begun to provide some general direction to clinicians in matching treatment to client problems. For example, Del Vecchio and O'Leary (2004) demonstrated that CBT is most effective in reducing anger expression, whereas cognitive therapy alone is better for problems in anger suppression. It is beyond the scope of this paper to review all of these studies, but a number of key findings and issues that Saini (2009) discusses in his most recent, and comprehensive meta-analysis deserve consideration. Saini evaluated the influence of a

number of moderator variables that were thought to have an influence on treatment effectiveness; his aim was to deconstruct the existing literature and provide an initial framework for evidence-based practice in the field. He found, like previous authors, a modest weighted overall effect size across studies (*d* =0.76), but with considerable variability for specific treatments of anger. This heterogeneity was moderated by the number of sessions offered, the use of manuals in guiding treatment, the use of treatment fidelity measures, the setting of the research and whether it had been published or not. Saini also found that the optimum number of treatment sessions was 8, after which outcomes improved very little, and attrition began to increase. Notably, 94% of studies reviewed were delivered to groups, so the findings are related predominantly to this format. He also found that community based treatment programmes had larger effect sizes than correctional facilities, psychiatric facilities and general hospitals.

Saini's (2009) analysis provides a useful guide to establishing some basic recommended components of an anger intervention. However, delivery of evidence-based practice is constrained by local resources, and the capacity to design, implement and deliver services differs vastly between countries, and even locally within a country. Hence, cost-effectiveness is yet another major consideration for any psychological treatment. Community-based psychology services provide a feasible means of meeting this economic demand, whilst also attempting to widen access of treatment to a larger population of people.

In the UK, there are currently a small number of anger management courses available, some offered by NHS services and some by voluntary organisations. As discussed in the 'Boiling Point' report on problem anger by the Mental Health Foundation (2008), there is a need to expand this provision, most likely through the Improving Access to Psychological Therapies (IAPT) programme. In order to do this though, it is imperative that the effectiveness of existing services is examined first. The only currently published empirical evaluations from non-forensic NHS services has come from one group in Southampton, who report promising results (Bradbury & Clarke, 2006; Naeem, Clarke, & Kingdon, 2009). Therefore, one of the current study's aims was to add to this literature by assessing effectiveness of a group based anger intervention (described below).

However, a problem recognised in this area of research has also been that anger interventions are often associated with high levels of attrition. Understanding the reasons for this is another key research question.

1.4 *A clinical challenge: Attrition in anger focused interventions*

Problems with attrition in angry clients are well documented, but the majority of this literature stems from assessment of correctional programmes for offending populations in countries outside of the UK (e.g. Wormith & Olver, 2002). In the UK, a handful of studies have documented similar problems via evaluation of forensic psychology services. For example, Dalton, Major, and Sharkey (1998) examined 219 forensic psychology outpatient referrals and found that out of a number of referral reasons (assessment only, tension/anxiety, sexual offending, theft/deception, violence, sexual abuse), anger was the most common reason for referral but had the poorest rate of assessment and completion of therapy (20%).
Similarly, Hird, Williams, and Markham (1997) assessed rates of attendance at anger control groups provided by Merseyside Forensic Psychology Service. They reported very low attendance, with only 18% completing the six-week course, and 19% only attending once. They consequently examined referral details to identify any characteristics that separated completers, partial completers and non-completers. They found that men in their oldest age bracket (34+) were most likely to attend. Source of referral had no influence on attendance; clients with external professional encouragement (e.g. the probation service) were more likely to attend their initial appointment, but thereafter had similar dropout rates to those without external professional motivation. However, clients with external pressure were further grouped according to whether there were potential consequences for non-attendance, such as from the State. Unsurprisingly, those who had likely consequences for non-attendance, such as increased probation period, had lower dropout rates at 39%, compared to 71% for those who were unlikely to suffer such consequences.

It will be useful to see if the findings from the forensic population can be extrapolated to the community workshops where non-offending, and likely lower risk, participants present to a typical NHS service. What is clear, however, is that motivation for attendance is a critical factor, and this is likely to be a problem common to all angry clients.

As mentioned above, to our knowledge there are only two existing peer-reviewed studies evaluating an established NHS service for anger problems in a non-offending sample. The first is Bradbury and Clarke's (2006) evaluation of an anger management service, where clients were offered 12 weekly group CBT sessions that focus primarily on arousal control. Data from one particular therapy group indicated that people who dropped out had significantly lower levels of self-esteem, and higher levels of depression at baseline than those who continued to attend. Moreover, those who remained in treatment saw significant improvements in anger

control and self-esteem, but not anxiety or depression. The second study is a small-scale randomised controlled trial (RCT) of this same service, which reports similar findings in a larger group of participants (Naeem *et al*., 2009). The authors conclude that low self-esteem and the hopelessness that is associated with depression are likely to interact and create low levels of motivation; hence, this echoes the findings about motivation from previous studies, but develops an account centred on ambivalence about attending. In their review on this topic, Howells and Day (2003) suggest that *readiness* for therapy is also a critical factor, which they describe as a broader and multifaceted concept as compared to simple 'motivation'.

In summary, there has been a limited amount of research regarding reasons for attrition in anger interventions. Furthering our understanding of this seems paramount in order to optimise the allocation of resources and manage waiting lists effectively in a publicly funded healthcare service. In the next section, we describe the particular NHS service on which the current study was based, highlighting our specific focus on the evaluation of efficacy and attrition.

1.5 *Group treatment for anger in Southwark Psychological Therapy Service*

Southwark Psychological Therapies Service (SPTS) is an IAPT service based in South-East London, serving the local Borough of Southwark. In response to an increasing number of self, and general practitioner (GP) referrals for anger problems, it was decided to set up a series of one-day low-intensity psychoeducational workshops grounded on CBT principles in 2011 (consisting of an initial introductory talk and all day workshop at a later date). This method of intervention was offered because it had been previously offered as part of a mental health promotion programme but stopped when the service moved into the IAPT service. Anger falls outside the range of psychological conditions covered in the stepped, or matched care model of IAPT, and is not covered by any current NICE guidelines. However, the programme was offered again when it was realised that no interventions were available for a number of people with anger problems who were presenting to the IAPT service.

This workshop format for up to 30 people was based on the effectiveness of other one-day programmes (e.g. self-confidence, insomnia) run by SPTS to reach the community. All participants completed a number of pre and post-workshop outcome measures, including anger, anxiety and depression, which provide the basis of our efficacy analysis below.

The drop-out rate between initial registration and the introductory talk was roughly comparable between anger, and other workshops. For example, over the course of four anger

workshops between June 2011 and December 2012, a total of 98 people were initially registered, but 38% of these did not attend the introductory talk afterward. In comparison, the drop-out rates were 40% and 45% for four 'increasing self confidence' and 'managing your sleep' workshops, respectively. However, and most critically, it was noted by staff that more people registered for anger workshops seemed to be dropping out following the introductory talk as compared to other workshops. Unfortunately it was not possible to directly compare the attendance pathway of participants at this stage between the actual workshops because of the way in which data was stored.

The high drop-out rate following the introductory talk creates a number of problems. For example, a large number of drop-outs mean that other people also in need of this relatively specialised treatment need to wait unnecessarily, or may even be excluded. On the other hand, it could be that those people dropping out have a high need for anger treatment, but the operation of the service means they feel unable to access it. In sum, reasons for attrition required exploration and staff in the service were keen to see the workshops continued; therefore a key priority for SPTS is to enhance both participation and outcomes in these anger based interventions.

1.6 *Aims of the present evaluation*

There were two broad aims of the current evaluation, which we hoped would answer the following questions:

a) Are the workshops helping people with their anger problems?
b) What are the reasons for the drop-out after referral? If, we know, can we provide recommendations to help improve the service?

1.6.1 *Hypotheses*

1) Evaluate psychological outcomes of the anger workshops

Previous RCTs have demonstrated the effectiveness of multiple session group CBT for anger, yet little research has examined the efficacy of lower intensity interventions. Given the evidence-base for use of CBT with this condition, we predicted that participants would experience a decrease in subjective anger over treatment. The measure used to quantify this was the Novaco Anger Inventory-short form (described below). Additionally, we predicted that successful treatment of anger may have positive effects on other

psychopathology, such as depression and anxiety. Although treatment generalisation is an under-researched area, some studies have found general improvements in depressive (Bradbury & Clarke, 2005) and anxiety symptoms (Deffenbacher, McNamara, Stark, & Sabadell, 1990; Gerzina & Drummond, 2000) in non-clinical populations; second, if a participant's anger is a component of a depressive or anxiety disorder (as discussed earlier), then it is reasonable to predict that these would reduce alongside measures of anger, if treatment is successful.

Our hypotheses were:

- Anger workshop participants will show a significant decrease in NAI-short form scores between baseline and one month follow-up.
- Anger workshop participants will also show significant reductions in depression (PHQ-9) and anxiety (GAD-7) scores between baseline and one month follow-up.

2) Identify factors that influence propensity to drop-out of treatment following referral

Using a similar line of enquiry as Bradbury and Clarke (2006), we aimed to explore if there were any defining characteristics of service users (SUs) when grouped according to whether or not they engaged in treatment following referral. Our hypotheses were largely based on the limited findings of previous similar research (Bradbury & Clarke, 2006; Hird *et al.*, 1997). Bradbury and Clarke (2006) found numerically higher scores in drop-outs on their measure of anger, but this was a non-significant difference. We therefore predicted a similar result in the current sample. These authors found significantly higher levels of depression in their drop-out group, which they suggested contributed to lower motivation; we therefore predicted the same pattern in our sample. We also reasoned that a cause for non-attendance of the workshop could be due to worry and anxiety about the group format. Therefore, we predicted higher levels of general anxiety in our non-attender group. We also assessed age, as Hird et al. (1997) found some evidence that older participants were more likely to attend their anger intervention.

In order to gain a richer understanding of people's reasons for dropping out, we also included a qualitative aspect of the evaluation and invited SUs to participate in a short, semi-structured interview. This asked for feedback for the whole referral to follow-up process. We hoped to hear this group describe reasons for non-attendance in their own terms, to complement the statistical differences in standardised psychological measures.

Our hypotheses were:

- There will be no difference in anger scores (NAI-short form) between attenders and non-attenders of the workshop;
- Non-attenders will show significantly higher levels of depression (PHQ-9) and anxiety (GAD-7) than attenders of the workshop;
- There will be a significant effect of age such that attenders of the workshop are older than non-attenders.

2. *Assessment of efficacy and attrition*

2.1 *Method*

2.1.1 *Design*

The quantitative aspect of this project utilised both a repeated measures design (to test for change in clinical scores before and after the workshops) and an independent measures design (to test for differences between groups, such as workshop attendance/non-attendance).

2.1.2 *Measures*

All participants were asked to provide demographic information and complete quite a large number of standardised measures as part of the workshop (at initial referral/intro talk, then repeated at the workshop and at follow-up).

There were two anger specific measures that were specially added for this study but most of the quantitative data had been collected routinely as part of the IAPT service. Information Governance approval was granted for the project by South London and Maudsley NHS Trust (ref#24-186356).

For the purposes of this study, we chose to omit a number of variables from our analysis (a full list of all measures taken can be found in Appendix I). The measures selected for analysis allowed us to test our hypotheses:

- Novaco Anger Inventory – Short Form (NAI-short form; Kidman, 1986, adapted from Novaco, 1975) This 25 item abbreviated version of the original Novaco scale asks participants to report the degree that anger would be provoked in various situations. Responses range from 'Very little' to 'Very much', with higher scores indicating a

higher propensity to be provoked into an angry state. The NAI-short form has been shown to reliably measure a single factor of 'anger', and in the same study displayed other satisfactory psychometric properties (Devilly, 2002). The scale has no established clinical cut-offs or normative data.

- State Trait Anger Expression Inventory – Second Edition (STAXI-2; Spielberger, 1999) This is a 57 item measure of the expression of anger, and is comprised of a number of subscales. For the purposes of the present study, only the overall anger expression index (AX) scale was used, where higher scores indicate higher total levels of anger expression. Normative data is provided in the manual, allowing percentile ranks to be calculated. The STAXI-2 has been used extensively in research and has been cross culturally-validated as a measure of anger expression (e.g. Maxwell, Sukhodolsky, & Sit, 2009). This was only used at baseline.
- Patient Health Questionnaire-9 (PHQ-9): The PHQ-9 is an instrument with 9 items that are based on the DSM-IV diagnostic criteria for depression. Each item can be scored from 0 (not at all) to 3 (nearly every day), indicating frequency of a range of depressive symptoms; higher scores indicate increasing severity of depression (cut-off = 10). Its reliability and validity as a diagnostic tool as well as its utility in assessing severity and monitoring treatment response are well-established (Kroenke, Spitzer, & Williams, 2001; Spitzer, Kroenke, & Williams, 1999).
- Generalised Anxiety Disorder-7 (GAD-7): The GAD-7 is a 7 item instrument that is used to identify probable cases of generalised anxiety disorder (GAD). It measures severity of anxiety symptoms by requiring responses indicating frequency over the past week: "not at all," "several days," "more than half the days," and "nearly every day." Item scores range from 0-3, as with the PHQ-9, with higher scores indicate increasing severity of anxiety (cut-off = 8). Its reliability and validity have been established as a tool for detecting GAD in the general population (Löwe *et al*., 2008), and it has been found to be moderately good at screening panic disorder, social anxiety disorder and post-traumatic stress disorder (Kroenke, Spitzer, Williams, Monahan, & Löwe, 2007).

Statistical Analysis

To assess differences in outcomes over two time points, paired samples t-tests were computed. Independent samples t-tests were used to test for between-group differences (attenders/non- attenders) at single time points in the attrition analysis. Alpha was set at $p < .05$ two-tailed throughout.

3. *Results*

There were two main strands to our analysis. First, we aimed to analyse differences in measures of anger, mood and anxiety for participants who attended the workshops and completed follow-up in order to evaluate the effectiveness of the group based anger intervention. Additionally, we wanted to investigate any potential differences between participants who chose to attend the workshop and those who did not. Specifically, we were interested in comparing the group who first attended the introductory talk and then not the workshop (from here onwards, called 'non-attenders'), with all participants who attended the workshop ('attenders').

3.1 *Participants*

In total, 50 participants (20 male, 29 female, and 1 unrecorded) attended the four workshops held over the course of 2011-2013. They had a mean age of 38.80 years (*sd* = 10.64). A full description of the pattern of attendance by each participant is provided in Tabl. The majority of participants attended both the introductory talk and workshop, a quarter attended the introductory talks but did not go on to attend the workshops and approximately one quarter did not attend the talk but did go to the workshop; this was part of how the workshops ran so that participants who were not able to come along to the talk could be offered a telephone assessment and then invited to come to the workshops. The first part of our analysis focuses on the psychological outcomes from the 50 attenders.

Table 1. Patterns of attendance by participants.

	N	Percentage (%)
Attended intro talk and workshop	33	50.00
DNA intro talk but attended workshop	17	25.76
Attended intro talk but DNA workshop	15	22.73
Attended neither	1	1.52
Total	65	100

Note: DNA = did not attend

3.2 *Effectiveness*

Table 2 displays outcome data for workshop participants. The varying numbers of participant data at baseline (T1) and follow-up (T2) reflect the fact that many participants' total scores could not be computed due to missing questionnaire items, despite all participants being asked to fully complete these measures.

The PHQ-9 and GAD-7 initial baseline scores are both just below clinical cut-off, suggesting that overall levels of depression and anxiety were moderate in this group. Overall anger levels are reasonably high as measured by the STAXI-2; that is, the average percentile suggests this group have self-reported anger that lies on the upper end of the normal distribution. Normative data does not exist for the NAI-short form, making it difficult to interpret scores in isolation.

Table 2. Baseline (T1) and follow-up (T2) scores on outcome measures for workshop participants.

Variable	T1 *N*	T1 Mean (SD)	T2 *N*	T2 Mean (SD)
PHQ-9	48	8.79 (6.83)	19	7.74 (6.33)
GAD-7	48	7.83 (6.21)	19	6.37 (5.84)
STAXI-2 (%ile)	19	83.05 (16.80)	-	-
NAI-short form	30	59.03 (18.48)	13	46.62 (21.59)

Note: Raw scores are presented unless otherwise stated. NAI-short form = Novaco Anger Inventory-short form (Kidman, 1986); STAXI-2 = State-Trait Anger Expression Inventory-Second Edition (Spielberger, 1999); PHQ-9 = Patient Health Questionnaire-9 item; GAD-7 = Generalised Anxiety Disorder-7 item.

Paired-samples t-tests were computed on the mean scores presented in Table 2 to assess the efficacy of the workshop intervention [1]. The number of participants included in this efficacy analysis is represented in the 'T2 *N*' column, which is smaller than T1 as it reflects the smaller number of people who provided data at both pre-treatment and follow-up.

[1] Unfortunately, STAXI-2 data were not obtained at follow-up so we were unable to calculate differences in self-reported anger expression over the different time points. Standardised measures were taken again at time of workshops, but a higher number of participants' data was missing for this time point, as compared to the baseline measures; therefore, to increase the *N* of the repeated measures analysis, baseline (i.e. pre- intervention) scores were used.

Anger was our key outcome measure, and in line with our hypothesis, NAI-short form scores were found to decrease significantly between pre-treatment and follow-up: $t(12) = 2.44$, $p = .03$, $d = 0.62$. This indicates that following the workshop, 43% (n=13) participants on average reported significantly lower levels of anger provocation. We also predicted decreases in mood and anxiety measures; although mean scores reduced following the intervention, the differences were non-significant for depression (PHQ-9: $t(18) = 1.51$, $p = .16$) and anxiety (GAD-7: $t(18) = 1.72$, $p = .10$).

Because the NAI-short form has little published psychometric data, we decided to check whether the reduction found above represents clinically reliable change, or can be accounted for by measurement reliability (*see* Jacobson & Truax, 1991). By using the standard deviation from the current sample at T1, and psychometric data for this scale derived from Devilly (2002), a reliable change score based on the Jacobson-Truax (1991) method would be an increase or reduction of 8.52. The reduction seen here was 8.36, which is almost identical. Therefore, there is approximately only a 5% chance that the significant difference in pre- and post NAI-short form scores was due to measurement error. In summary, it appears that the intervention did reduce people's self-reported anger provocation.

3.3 *Quantitative analysis of attrition*

Following the above analysis of efficacy, we next examined possible reasons for attrition. Table 3 displays the mean (*sd*) for the measures described in section 2.1.2, as well as age. The 'Attendance' column represents participants who came to the workshop (Yes) and those that came to the introductory talk, but not the workshop (No). Each mean score is the pre-treatment baseline. Independent t-tests and associated *p* values are also presented for comparison between attenders and non-attenders. Overall, this analysis provides no evidence of significant differences in any measure, although a non-significant trend was found in GAD-7 scores such that non-attenders were slightly more anxious. Therefore, our hypotheses were disconfirmed as it was predicted that non-attenders would have significantly higher depression and anxiety levels and be significantly older as a group than attenders. As for anger, there were lower scores in the non-attenders on one measure (NAI-short form) and higher in the other (STAXI-2) suggesting no reliable difference in subjective anger between groups.

In summary, the evidence accumulated thus far indicates little to differentiate between non-attenders and attenders.

Table 3. Group differences between those attending and not attending workshop.

Variable	Attendance	*N*	Mean (SD)	*t*	*p* value
Age	Yes	50	38.80 (10.64)	.28	.78
	No	15	37.93 (9.99)		
PHQ-9	Yes	48	8.79 (6.83)	.77	.45
	No	15	10.40 (7.88)		
GAD-7	Yes	48	7.83 (6.21)	1.79	.08
	No	15	11.07 (5.75)		
STAXI-2 (%ile)	Yes	19	83.05 (16.79)	1.08	.29
	No	6	91.17 (13.30)		
NAI-Short Form	Yes	30	59.03 (18.48)	.63	.53
	No	8	54.25 (21.22)		

Note: Raw scores are presented unless otherwise stated. NAI-short form = Novaco Anger Inventory-short form (Kidman, 1986); STAXI-2 = State-Trait Anger Expression Inventory-Second Edition (Spielberger, 1999); PHQ-9 = Patient Health Questionnaire-9 item; GAD-7 = Generalised Anxiety Disorder-7 item.

3.4 *Qualitative analysis of attrition*

Our aim was also to gain qualitative feedback from SUs regarding their experience of the workshops – from initial referral through to follow-up. Our target group were the SUs who had decided not to attend following initial referral or after the introductory talk. We hoped by speaking to even a small number of these people that we would gain a richer understanding of the reasons people dropped out. Responses from other participants who attended the workshop would also be valuable, as service improvement should always be driven by this kind of feedback.

3.4.1 *Method*

3.4.1.1 *Materials and Procedure*

We developed a semi-structured interview to be administered via telephone (see Appendix II). In brief, the questionnaire asked about participants' satisfaction with each stage of the service: referral, introductory talk, workshop and follow-up. We requested positive feedback, as well as suggested areas for improvement. Information Governance approval was granted by South London and Maudsley NHS Trust on the basis that 'consent to contact' letters were first sent to

participants. Participants indicated consent to be telephoned by returning a postal slip; they were subsequently contacted and provided more information about the purpose of the project before verbally consenting to take part in the interview.

3.4.1.2 *Data collection and analysis*

Out of the 65 participants registered across the four workshops, a total of 58 SUs were contactable by post; nine of these replied with the consent slip and only six were able to be finally contacted by telephone. All of these six people participated in the interview, but none of them were SUs in the target group explained above. For this reason, we decided not to include an analysis of those findings here; notably, however, the six participants provided a relatively balanced opinion of the workshops, giving both positive and negative feedback.

Although our main intention was to interview SUs who decided not to attend the workshops, the fact that we only received responses from those who did attend is a finding in itself, but we can only hypothesise as to the reasons this group would be unwilling to engage in discussion about their reasons for not attending.

4. *Discussion*

This service evaluation firstly aimed to evaluate the effectiveness of Southwark Psychological Therapy Service (SPTS) one-day anger interventions primarily by assessing changes in subjective anger, but also a range of other psychological outcomes. The workshops were found to be effective in reducing participants' self-reported level of anger provocation, but no significant reductions were found in depression and general anxiety levels. A secondary aim was to identify factors that influence the propensity to drop-out following referral. We found a tendency for non-attenders to be more anxious than those who attended. However, no other significant results were obtained. Moreover, we were unable to elaborate on this finding in the qualitative arm of our study due to none of the non-attenders of workshops consenting to be interviewed.

4.1 *Effectiveness*

Our findings add to the emerging literature on psychological treatment of anger and suggest that low intensity interventions such as a one-day cognitive-behavioural based workshop are also effective. We found a moderate uncontrolled effect size (d=0.62) which is consistent with

the findings of several recent meta-analyses, which have tended to include studies involving treatments lasting several weeks and undergraduate students as the most common participants (Beck & Fernandez, 1998; DiGiuseppe & Tafrate, 2003; Saini, 2009; Tafrate, 1995). It must be acknowledged, however, that these studies tend to use controlled effect sizes due to the comparison of treatment vs. control group outcome measures; we were not in a position to do this.

In the most up-to-date synthesis of these findings, Saini (2009) made a number of conclusions regarding the optimum treatment package for different anger problems. His analysis found the following to have the best outcomes overall: an individual therapy format; approximately 8 sessions; University or community settings rather than forensic or correctional facilities; and treatment administered directly from a manual with fidelity checks in place. The current relatively new intervention was delivered via a manual and in a community setting, but was not individual or spread over several sessions. Moreover, he highlighted that exposure therapy had the highest effect size for measures of anger provocation, and that psychoeducational approaches often had below moderate effect sizes. Here, we in fact found moderate effects on anger provocation with a purely psychoeducational treatment. Although variability is to be expected between studies, our results, derived from a series of groups, suggest this is a promising approach.

Our results showed that there was no significant treatment generalisation beyond anger to depression and anxiety symptoms. Although a reduction in such scores has been found in previous studies (Bradbury & Clarke, 2006; Deffenbacher et al., 1990; Gerzina & Drummond, 2000), it is likely that methodological differences and heterogeneity of samples across these has created variability in findings. For example, although the workshops lasted for about seven hours, other studies have an increased frequency of treatment due to multiple sessions, which may afford the opportunity to focus on practising therapeutic skills in-between each week. Additionally, depression and anxiety levels were not particularly high overall in the current study, so it is possible that people with initial baseline scores falling further into in the clinical range may be more likely to experience significant reductions in these symptoms, alongside anger. Furthermore, participants may have experienced improvements in areas that were not captured by the objective measures collected by the service. For example, following an anger intervention other authors have found improvements in measures of self-esteem and beliefs regarding the way others perceive them (Naeem *et al*., 2009). However, clinical change in other psychological outcomes was a secondary aim for the workshops, given that the focus of the current groups was specifically to help with anger problems.

4.2 *Attrition*

Attrition is recognised as a major challenge in the treatment of anger, including our own service, yet few studies have specifically examined potential explanations for this. Our predictions were not met with respect to attenders and non-attenders of groups, as we found no discernible differences between them on any outcome measure. These predictions were derived from the handful of previously published studies on this topic. Two of these are based on forensic psychology outpatient services (Dalton *et al*., 1998; Hird *et al*. 1997), which likely receive referrals with a greater severity of problem anger, as well as a different referral route, with many offenders being referred for services against their own wish. Nevertheless, these two studies tended to find that older men (> 30) were the most likely to remain in treatment. To our knowledge, the only existing study to examine attrition in a similar non-clinical or forensic NHS setting is Bradbury and Clarke's (2006) small-scale analysis of one particular anger management group. They found that patients who dropped out had higher initial depression scores and lower self-esteem. They suggested that withdrawal, lack of energy and motivation associated with depression may explain why people would drop out of an anger intervention.

Motivation to attend appears to be the most consistently discussed topic in this area, and this is explored in depth within Howells and Day's (2003) critical commentary on *readiness* for anger treatment. These authors suggest that if the person is being pressured by someone else to seek treatment for anger, and they believe their anger is appropriate for themselves and take a position of low responsibility, then they are not likely to engage with treatment. Although our referrals were likely to have had less external pressure placed upon them than, for example, a court order for anger rehabilitation, it is still possible that pressure from family members and partners existed. This would also explain why non-attenders did not respond to our invitation to a telephone interview. Alternatively, it may be that non-attenders of the workshop felt embarrassed or ashamed of their difficulties. In support, research suggests that maladaptive responses to anger are often linked to high shame-proneness (Tangney, Wagner, Hill-Barlow, Marschall, & Gramzow, 1996). Thus, although we did not find significantly higher levels of anger in the non-attender group, it could still be that these people experience other emotions (e.g. shame and guilt) in response to their anger which stopped them from coming back or participating in our interview. The elevated levels of anxiety in this group are also worth noting; it may mean such people are simply more nervous about participation in any engagement with services, be it group-therapy or a telephone interview.

We must be careful, however, to assume that reasons for drop-out from treatment can be easily located within the individual; another viable explanation is that the nature of the service is somehow not meeting this group of people's needs. As Ward, Day, Howells, and Birgden (2004) discuss, it could be an issue with internal and external responsivity. Internal responsivity requires a therapist who pays close attention to client attributes such as personality and intellectual ability and tailors content and pace of sessions accordingly. External responsivity refers to aspects of the particular setting of the therapy, or characteristics of the staff. Thus, participants who attended the introductory talk but later dropped out may have felt the service did not meet these responsivity needs. Of course, we had hoped to elucidate this through the interviews. However, from the small number of respondents who did attend the workshops, the consensus was that the group facilitators' approach and the nature of the setting were satisfactory.

4.3 *Limitations*

We recognise several limitations in the present evaluation. First, our follow-up analysis was based on about 40% of participants. The follow-up data for our anger measure is based on 43% of those who completed the NAI measure. The completion rate was 39.6% at follow-up for the PHQ-9 and GAD-7. Encouraging all participants to complete the measures fully in future is a way of targeting this problem, but there are clearly some practical limitations to this, such as the constraints on time of clinical staff to chase participants for follow-up data.
Another potential limitation is that the small number of participants completing follow-up data represent a different group altogether compared to those who did not complete these questionnaires. For example, they may have been the participants who felt the most subjective improvement, whereas those not completing questionnaires were the more severe cases who saw no gains. To check this, we ran further analyses comparing anger, depression and anxiety scores between follow-up completers and non-completers and found no difference in any measure, suggesting the above interpretation is not true.

Finally, we were only able to ascertain differences on one particular anger measure; as anger is a multifaceted construct it would be useful to evaluate if the intervention had an effect on aspects of the problem other than just provocation. Obtaining follow-up data with the STAXI-2 would be ideal, as this measure provides several subscales, hence its ubiquitous use in previous research.

4.4 *Further directions and research*

Given the relative scarcity of anger research in comparison to other psychological disorders, there is scope for an enormous amount of future work in this area. A sizeable body of treatment effectiveness studies exist globally, but it would be beneficial if other NHS services endeavoured to publish results from other non-forensic services, as this will help in raising the profile of problem anger, and spark interest in an area in desperate need of elaboration and diagnostic clarification. Current evidence suggests individual high-intensity treatment is the most effective for problem anger (Saini, 2009) but it would be useful for future research to replicate the present results and further demonstrate efficacy of low-intensity interventions that are more economically viable. It also seems paramount that research continues to explore moderators of treatment effectiveness, and understand more about how anger manifests differently in certain types of people (e.g. those with co-morbid mental health conditions, or younger and older individuals). Given the problems with high dropout rates, research should identify ways of preventing this and removing barriers to treatment. Although we found limited evidence in the present study to help explain the attrition phenomenon, knowledge will no doubt accumulate over time if future studies keep this as a research agenda. It is likely that a major factor is the stigma associated with problem anger, as well as such variables as motivation, as discussed earlier. As the recent report on problem anger from the Mental Health Foundation (2008) recommended, not only does there need to be an increased provision of pathways for those seeking help with this condition, there also needs to be more provision of education related to anger management in various settings, aimed at children, adolescents and adults.

4.5 *Clinical implications*

The key clinical implication of this evaluation is that the brief, one-day intervention can provide meaningful help with problem anger. Specifically, this appears to come in the form of a greater sense of control over what kind of things are likely to be interpreted as threatening, or provoking. Problem anger is prevalent in society and health care professionals should be aware that effective treatments such as that presented here do exist.

Given the other main aim of this evaluation was to begin to understand why attrition is high, the implication of our findings is that there appears to be no straightforward answer. If we had discovered specific groups of people most likely to not attend, then we would have perhaps been able to adjust the service in some way to accommodate this finding. For example, if it is anxiety about attending, a further phone call from a group facilitator to reassure the participants. However, the available evidence suggests that addressing motivation may be the

most important factor. Therefore, services may wish to adopt some of the ideas developed in the screening procedure used by Naeem et al. (2009) in their non-forensic NHS anger service. Their screening involved: the dimensions of the anger problem for that person and its impact on their life and relationships; their ability to make the connections between physical arousal, thoughts and feelings necessary for a cognitive behavioural approach; their willingness to relinquish threat and violence as a means of regulating relationships; their commitment to attend regularly and complete homework. The authors report that this process eliminated a considerable number of people who had attended through the pressure of others. This process may be quite time consuming, however, so perhaps a briefer and more general assessment of motivation would be more pragmatic.

5. *Dissemination*

As of May 2015, the project has been adapted and submitted for publication in The Journal of Community Psychology. The results have also been summarised and distributed in a newsletter around SPTS, and presented to some of the workshop leaders.

6. *Leadership*

On a local scale, leadership has been demonstrated in the ability of this work to aid future service development for this particular IAPT service - or at the very least, give staff a better understanding of the intervention that is being delivered and how it may (or may not) be effective for different people. At a wider level, publication of this article in a small and under researched field could make an important contribution to the area and provide useful information for other NHS services running similar programmes, or for those wishing to design a similar intervention.

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8. *Appendices*

8.1 *Appendix I: Full list of questionnaires and information retrieved from workshop participants*

Demographic questions

Age
Gender
Relationship status
Occupation
Ethnicity
Religion

Clinical questions

Are you taking medication for anxiety or depression? If yes, what medication?
Have you tried counselling or psychological help before? If yes, provide details.
How did you hear about the workshops?
What would you like to gain from the workshops?
What is the main difficulty for which you would like help?
Have you ever experienced anxiety problems? If yes, how long have you had them?
Have you ever experienced depression problems? If yes, how long have you had them?
Have you ever sought help from your GP for these problems?
If you have not consulted your GP, why not?
If you are working (at T1), how many days off sick have you had in the past 3 months?
If you aren't working (at T1), how many days 'out of role' have you had in past 3 months?

Objective measures

PHQ-9
GAD-7
IAPT Social Phobia Scale
IAPT Specific Phobia Scale
IAPT Panic Disorder Scale
IAPT Employment Status
Work and Social Adjustment Scale
Novaco Anger Inventory-short form (NAI-short form)
State-Trait Anger Expression Inventory-Second Edition (STAXI-2)

8.2 *Appendix II: Semi-structured interview schedule*

Opening statement:

Thank you for agreeing to be contacted regarding our project on the anger workshops at SPTS. As mentioned briefly before, we are interested in hearing participants' views to help us improve the delivery of these workshops, as this is a new programme we have started. For people who attend all stages, we would like to know about the things they found most helpful and beneficial to them, and the things you think could be improved – this might be related to things like the way the referral process worked, the people who ran the introductory talks/workshops, the content of the workshops, or the place and time they were held.

A number of people decided not to come to the workshop after the introductory talk, whereas some decided to go right through the workshop. We are particularly interested in how come you made the decisions you did. We know from similar previous research from other services offering anger interventions that there are many reasons people decide not to engage in workshops – for example, sometimes people have found they feel awkward about coming or really anxious, which is completely understandable when faced with participating in a larger group. We would like to know if it is these sorts of things which led to a decision not to attend, or if there are things about the service which put people off.

If you are still happy to go ahead, I will just be asking you some general questions with some follow-ups to get your views. Is it OK to go on?

For those who attended the workshop (Intro talk and workshop)

1) Referral

Did you self-refer, or were you referred by someone else? Who was it?

If referred by someone else, were you happy with the process in terms of how it was explained to you, how long it took until the introductory talk and workshop etc?

2) Introductory talk

Next I would like to ask you about the introductory talk. Did you find the talk provided you with an accurate picture of what was to be expected in the final workshop?

What were the things you liked about the talk?

As you attended the workshop, are there any ways you think we could improve the introductory talk to prepare people better?

3) Workshops

Next I would like to know about your experience of the workshop itself.

What was your overall impression of the anger workshops?

What did you find most helpful? E.g. content, delivery, location, group size.

Would you recommend this workshop to others experiencing similar problems? Yes/No and Why?

Were there any specific aspects you think we could improve on? E.g content delivery, information about further help, location, group size.

4) Follow-up

Finally, I would just like to know briefly your thoughts on the follow-up.

Did you appreciate having the follow-up, or did you feel it was unnecessary?

Did you think it was appropriately timed, or should it have been sooner/longer after the workshop?

5) Closing

Thank you for your time today, your opinions really matter to us and hopefully we can improve the service using the information you have provided. Is there anything else you would like to add?

For those who attended introductory talk but then dropped out, the 'referral' and 'closing' sections are the same but the following is changed:

Introductory talk

I understand that you decided not to attend the actual workshop following the talk, so I was just wondering if there was something in particular that put you off during the talk?

Was there anything you liked about the talk?

In the future do you have any suggestions as to how we could improve the introduction? Is there something we could have changed which would have made you feel more able to come along to the workshop? For example, was it in an inconvenient location for you, or did you feel awkward about being in a larger group of people?

Were there other things that stopped you coming along which we would not be able to address? For example, child care issues, or illness?